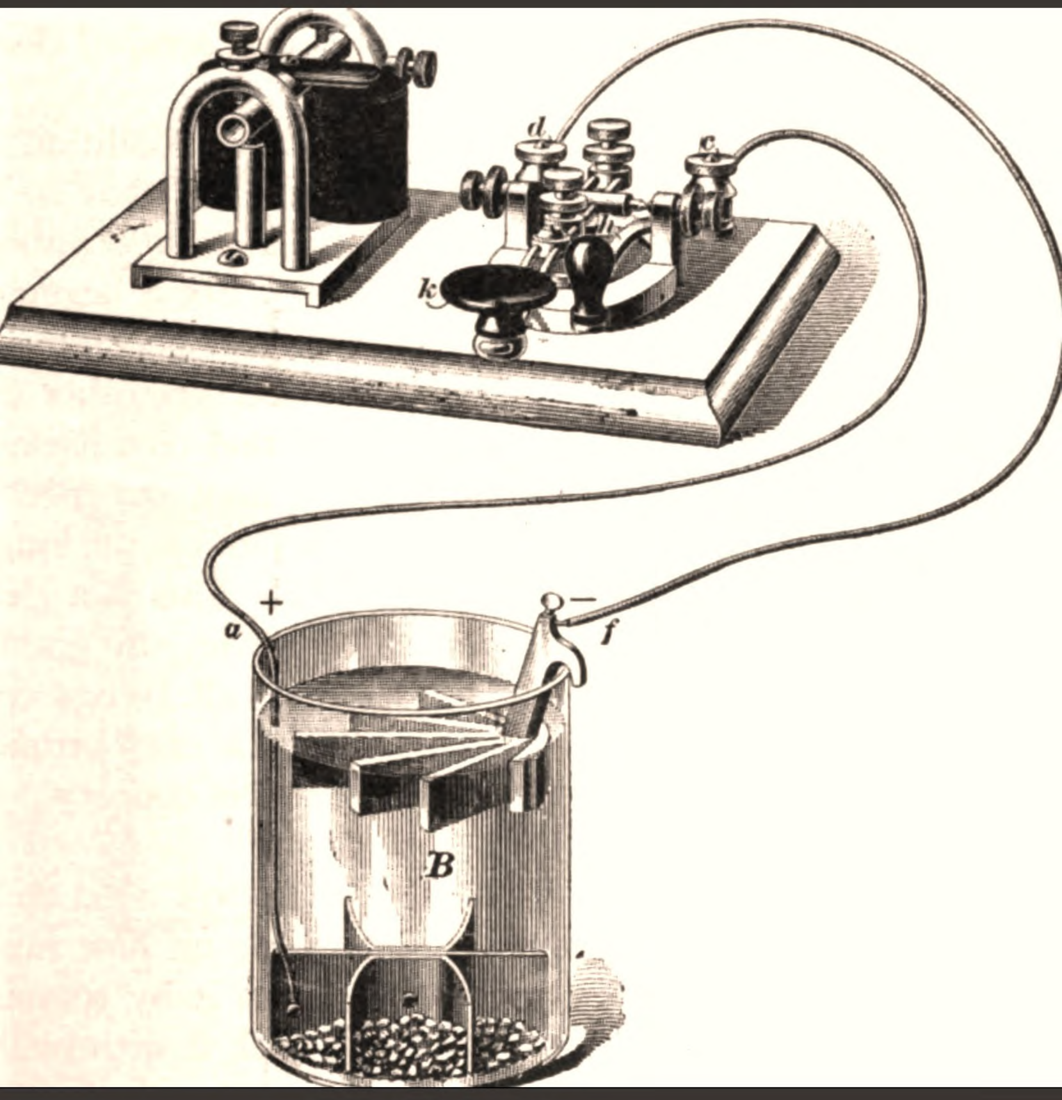

Elements of telegraph operating ; Elementary telegraphy ; ...

International Correspondence Schools

INTERNATIONAL LIBRARY OF TECHNOLOGY

A SERIES OF TEXTBOOKS FOR PERSONS ENGAGED IN THE ENGINEERING PROFESSIONS AND TRADES OR FOR THOSE WHO DESIRE INFORMATION CONCERNING THEM. FULLY ILLUSTRATED AND CONTAINING NUMEROUS PRACTICAL EXAMPLES AND THEIR SOLUTIONS

ELEMENTS OF TELEGRAPH OPERATING
ELEMENTARY TELEGRAPHY
TELEGRAPHY
TELEGRAPH REPEATERS
POWER EQUIPMENT

SCRANTON:
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PREFACE

The International Library of Technology is the outgrowth of a large and increasing demand that has arisen for the Reference Libraries of the International Correspondence Schools on the part of those who are not students of the Schools. As the volumes composing this Library are all printed from the same plates used in printing the Reference Libraries above mentioned, a few words are necessary regarding the scope and purpose of the instruction imparted to the students of—and the class of students taught by—these Schools, in order to afford a clear understanding of their salient and unique features.

The only requirement for admission to any of the courses offered by the International Correspondence Schools, is that the applicant shall be able to read the English language and to write it sufficiently well to make his written answers to the questions asked him intelligible. Each course is complete in itself, and no textbooks are required other than those prepared by the Schools for the particular course selected. The students themselves are from every class, trade, and profession and from every country; they are, almost without exception, busily engaged in some vocation, and can spare but little time for study, and that usually outside of their regular working hours. The information desired is such as can be immediately applied in practice, so that the student may be enabled to exchange his present vocation for a more congenial one, or to rise to a higher level in the one he now pursues. Furthermore, he wishes to obtain a good working knowledge of the subjects treated in the shortest time and in the most direct manner possible.

In meeting these requirements, we have produced a set of books that in many respects, and particularly in the general plan followed, are absolutely unique. In the majority of subjects treated the knowledge of mathematics required is limited to the simplest principles of arithmetic and mensuration, and in no case is any greater knowledge of mathematics needed than the simplest elementary principles of algebra, geometry, and trigonometry, with a thorough, practical acquaintance with the use of the logarithmic table. To effect this result, derivations of rules and formulas are omitted, but thorough and complete instructions are given regarding how, when, and under what circumstances any particular rule, formula, or process should be applied; and whenever possible one or more examples, such as would be likely to arise in actual practice—together with their solutions—are given to illustrate and explain its application.

In preparing these textbooks, it has been our constant endeavor to view the matter from the student's standpoint, and to try and anticipate everything that would cause him trouble. The utmost pains have been taken to avoid and correct any and all ambiguous expressions—both those due to faulty rhetoric and those due to insufficiency of statement or explanation. As the best way to make a statement, explanation, or description clear is to give a picture or a diagram in connection with it, illustrations have been used almost without limit. The illustrations have in all cases been adapted to the requirements of the text, and projections and sections or outline, partially shaded, or full-shaded perspectives have been used, according to which will best produce the desired results. Half-tones have been used rather sparingly, except in those cases where the general effect is desired rather than the actual details.

It is obvious that books prepared along the lines mentioned must not only be clear and concise beyond anything heretofore attempted, but they must also possess unequaled value for reference purposes. They not only give the maximum of information in a minimum space, but this information is so ingeniously arranged and correlated, and the

indexes are so full and complete, that it can at once be made available to the reader. The numerous examples and explanatory remarks, together with the absence of long demonstrations and abstruse mathematical calculations, are of great assistance in helping one to select the proper formula, method, or process and in teaching him how and when it should be used.

This is the first of a set of three Volumes covering in a comprehensive manner the subject of Telegraphy. The instruction is based on the experience gained by many years of teaching this profession and on a careful study of modern telegraph systems. This volume treats of the principles underlying the art of telegraphy, and includes practical directions for acquiring skill in sending and receiving messages, as well as very complete descriptions and numerous illustrations of the apparatus used in the simpler telegraph systems. The operation, care, and adjustment of keys, relays, sounders, and registers, are explained; the switchboards used for this service are described; and the properties of circuits, such as resistance, inductance, and capacity are stated and their effects on operation noted. Included in the Volume is a very complete treatise on the power equipment of telegraph stations, covering motors, generators, rotary converters, current rectifiers, storage batteries, and other devices. The various subjects have been so presented that the instruction will be of real value to the beginner, to the operator, or to the engineer engaged in the construction, installation, and maintenance of telegraph systems.

The method of numbering the pages, cuts, articles, etc. is such that each subject or part, when the subject is divided into two or more parts, is complete in itself; hence, in order to make the index intelligible, it was necessary to give each subject or part a number. This number is placed at the top of each page, on the headline, opposite the page number; and to distinguish it from the page number it is preceded by the printer's section mark (§). Consequently, a reference such as § 16, page 26, will be readily found by looking along the inside edges of the headlines until § 16 is found, and then through § 16 until page 26 is found.

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CONTENTS

ELEMENTS OF TELEGRAPH OPERATING

INTRODUCTION

1. The operation of telegraphic apparatus is not, as many people suppose, a very complicated and difficult matter to understand; but to become a first-class operator requires constant practice and the acquisition of information on every practical point connected with the apparatus and the operation of the instruments.

A person can usually become fitted, in 4 or 5 months of steady practice, to take a position in a small telegraph office; while, if proper diligence is exercised, 1 to 2 years of experience should enable one to become a first-rate operator. It is always much easier for a skilled operator to secure steady employment at first-class wages than it is for a third- or a fourth-rate operator to obtain employment, even at the lowest rates. In order to become an expert operator, the best time to learn is between the ages of fifteen and twenty-five.

2. The systematic and continual practice that should be pursued may be divided, broadly, into three classes: (1) Morse writing with the key, and without a companion. (2) Combined Morse writing and reading with a companion student in the same room. (3) Practice in Morse writing and reading of messages, social conversation, and printed matter, the two persons practicing being in different rooms or houses.

The first step is to memorize the Morse alphabet and to practice making the characters with the key. This can be

done alone. A person should become so familiar with the Morse signals that no more effort will be required to make the Morse characters of a word on a key than to write the letter on a piece of paper.

The second step consists in key writing or sending by one person, while another tries to read the words that are sent, and, as far as possible, to copy them. Considerable practice at this work is necessary, in order that the student may become perfectly familiar with the sound of the Morse letters. The two persons should alternately send and receive. This practice serves to correct inaccuracies in sending the signals, for each one must make the signals correctly, or they cannot be read by the other.

3. As soon as learners have become able to hold a conversation of short sentences in "Morse" with each other, they should begin the separated practice; that is, with the instruments set up in separate rooms or houses and connected as explained later, they should practice sending and receiving, copying everything as it is received. The persons practicing should be entirely dependent on the telegraphic apparatus for their communication. Whenever it is possible, practice should be completed in a telegraph office. A few weeks of such work will familiarize one with office routine, and will give, besides, an excellent opportunity to practice reading by sound and copying the constantly passing messages of various kinds.

TELEGRAPH CODES AND APPARATUS

CODES

THE MORSE CODE

4. Following are given in a convenient form the characters in the Morse code representing the letters in the English alphabet, and the characters in the Phillips code representing punctuation and other marks. These are the characters in common use in the United States and Canada, except for submarine telegraphy and most wireless telegraph stations, for which the Continental code is used.

In America, on circuits equipped with the Wheatstone apparatus, the Morse code is used, except that two dots and two dashes (figure 7 reversed) are used for the letter *l*. The **Morse code** of letters and numbers is as shown herewith.

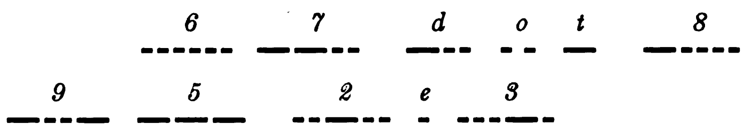
ALPHABET

A	*B*	*C*	*D*	*E*	*F*	*G*
· —	— · · ·	· · ·	— · ·	·	· — ·	— — ·
H	*I*	*J*	*K*	*L*	*M*	*N*
· · · ·	· ·	— · — ·	— · —	———	— —	— ·
O	*P*	*Q*	*R*	*S*	*T*	*U*
· ·	· · · · ·	· · — ·	· · ·	· · ·	—	· · —
V	*W*	*X*	*Y*	*Z*	&	
· · · —	· — —	· — · ·	· · · ·	· · · ·	· · · ·	

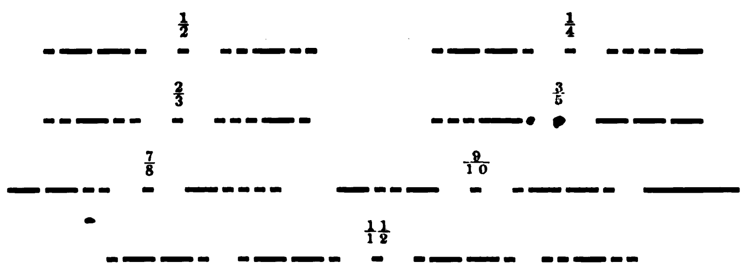
NUMERALS

1	*2*	*3*	*4*	*5*
· — — ·	· · — · ·	· · · — ·	· · · · —	— — —
6	*7*	*8*	*9*	*0*
· · · · · ·	— — · ·	— · · · ·	— · · —	———

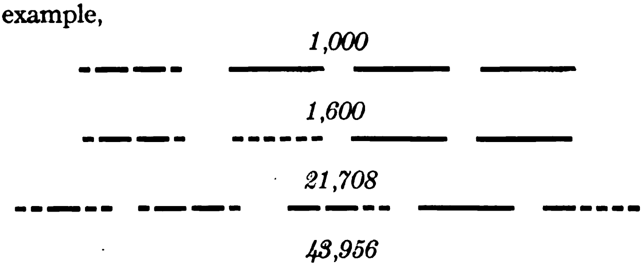
The decimal point is transmitted by spelling out the word *dot*. For instance, 67.895⅔ is transmitted *67 dot 895 2 e 3*; thus,



5. Fractions.—Fractions are made by substituting a dot for a hyphen between the figures.



6. Large Numbers.—In large numbers, it is well at first to make a larger space than usual between every three figures; for example,



However, in actual practice it is more often customary to make a larger space only between every three ciphers in groups of six or more ciphers. As in the Morse code, three ciphers, when sent quickly, resemble the figure 5, *tnd* is used to express thousands and *myn* to express millions, when the last three or six figures are ciphers exclusively. Thus, 10,000 is transmitted *10 tnd;* and 267,000,000, *267 myn.* Hundreds may be

advantageously expressed by *hnd*. Thus, 300 is transmitted *3 hnd*; and 400,000, *4 hnd tnd*. Two hundred thousand dollars may be transmitted in either of the following two ways:

s x 2 h n d t n d

s x

2 0 0 0 0 0

PHILLIPS PUNCTUATION CODE

7. The **Phillips punctuation code** has superseded the Morse because it is much more complete and systematic.

.	Period	
,	Comma	
:	Colon (*KO*)	*K O*
:—	Colon dash (*K X*)	*K X*
;	Semicolon (*SI*)	*S I*
?	Interrogation	
!	Exclamation	
-	Fraction line (*E*)	
—	Dash (*DX*)	*D X*
-	Hyphen (*HX*)	*H X*
,	Apostrophe (*QX*)	*Q X*
$	Dollars (*SX*)	*S X*
c	Cents (*C*)	*C*
£	Pound sterling (*PX*)	*P X*
/	Shilling mark	

d	Pence (*D*)	*D*
.	Decimal point	
	Capitalized letter (*C X*)	*C X*
¶	Paragraph	
:“	Colon followed by quotation (*K Q*)	*K Q*
( )	Parenthesis (*P N*)	*P N P N*
or (	at beginning (*P N*)	*P N*
)	at end (*P Y*)	*P Y*
“ ”	Quotation (*Q N*)	*Q N Q N*
or “	at beginning (*Q N*)	*Q N*
”	at end (*Q J*)	*Q J*
“ ‘ ’ ”	Quotation within a quotation (*Q X*)	*Q X Q X*
	Underline or Italics (*U X*)	*U X*
or	at beginning (*U X*)	*U X*
	at end (*U J*)	*U J*
[ ]	Brackets (*B X*)	*B X B X*

DOTS, DASHES, AND SPACES

8. The dot is taken as the unity by which the lengths of the dashes and spaces are measured. The relative lengths of the different dashes and spaces are as follows:

Signal	Duration of Signal
Dot	1 unit
The dash	3 units
The long dash (*l*)	6 units
The extra-long dash (cipher)	9 units
Space between parts of a letter	1 unit
Space in spaced letters	2 units
Space between letters	3 units
Space between words	6 units

It will be noticed that there are four lengths of spaces and three of dashes, or four including the dot. Expert operators, in order to shorten the time of sending, make a space of ½ unit between parts of a letter and 5 units between words. Beginners, however, should make the full space of 1 unit between parts of letters and of 6 units between words; the shorter spacing will gradually be acquired by the time one is able to send good Morse at a fair speed.

9. The dot *e* is made by a single instantaneous downward stroke of the key. On the sounder a dot is indicated by a down stroke immediately followed by an up stroke. A dash *t* is made by holding the key down as long as it takes to make 3 dots. On the sounder, the short dash is indicated by a downward stroke followed, after an interval of 3 dots, by an upward stroke. A long dash *l* is made by holding the key down as long as is required to make 5 dots, the 5 dots and 1 break making the 6 units.

The extra-long dash *0* (cipher) is prolonged so as to occupy the time required for 7 dots. Theoretically, the extra-long dash should be one-half longer than the long dash; that is, 9 units in length when the dash is made 6 units. However, in practice, the *l* and the *0* are generally made the same; occurring alone, the long dash would be read as *l*, but when found among figures it would be translated as *0* (cipher). This has not been found to cause any inconvenience. The theoretical value for the extra-long dash will always be given here, but it may be shortened at least to 7 units.

When the art of sending and receiving has been thoroughly acquired, the length of the dash, long dash, and extra-long dash may be shortened as follows: Dash to 2 units; long dash to 4 units; and extra-long dash to 5 units. This will be done unconsciously in rapid sending. By thus shortening the dashes, a material gain in rapidity of transmission is effected without any great disadvantage. Where recording instruments are used for receiving, this shortening of the dash is not advisable, for it is then very easy to mistake a dash for a dot.

10. Breaks and Spaces.—The intervals between dots or dashes in the same letter are called **breaks,** and in letters that do not contain spaces, the dots and dashes should follow one another as closely as possible. But in the letters

O *C* *R* *Y* *Z* &

▪ ▪   ▪▪ ▪   ▪ ▪▪   ▪▪ ▪▪   ▪▪▪ ▪   ▪ ▪▪▪, which are termed *spaced letters*, there is in each a break that is just double that ordinarily used between the elements of a letter; that is, each has in it a break equivalent to the time necessary to make 2 dots or 1 dot and 1 break. Such a space is indicated on the sounder by the interval of the duration of a dot between an upward stroke and the next succeeding downward stroke, that is, 2 units between the instant of breaking and the next make; the up-and-down motions occupy about 1 unit of time.

The **space** between letters should occupy the time required for 2 dots and a break, or 3 units. The space between words should occupy the time required for 6 units; that is, the key remains against the upper contact for 5 units, the up-and-down motion occupying 1 unit of time.

MEMORIZING THE MORSE CODE

11. In the first place, it is necessary to memorize the Morse alphabet—not in alphabetical order, but in such a way that any character can be called to mind at will. It is sometimes a help and advisable when memorizing the letters to try to make them with the telegraph key. The period, comma, and interrogation are the only punctuation marks in frequent use, and are the only ones with which the beginner need at first concern

himself. The Phillips punctuation code, however, should be learned and not the Morse. By grouping the letters in the following manner, they can be learned much more readily than when in alphabetical order and with less labor:

DOT CHARACTERS

E	*I*	*S*	*H*	*P*	*6*
.	..	...	....	.....	......

SPACED CHARACTERS

O	*C*	*R*	*Y*	*Z*	&
. .	.. .	. ..	.. ..	... .	. ...

DASH CHARACTERS

T	*L*	*M*	*5*	*0*
—	——	— —	— — —	———

DOT-AND-DASH CHARACTERS

A	*U*	*V*	*4*
.—	..—	...—	....—

DASH-AND-DOT CHARACTERS

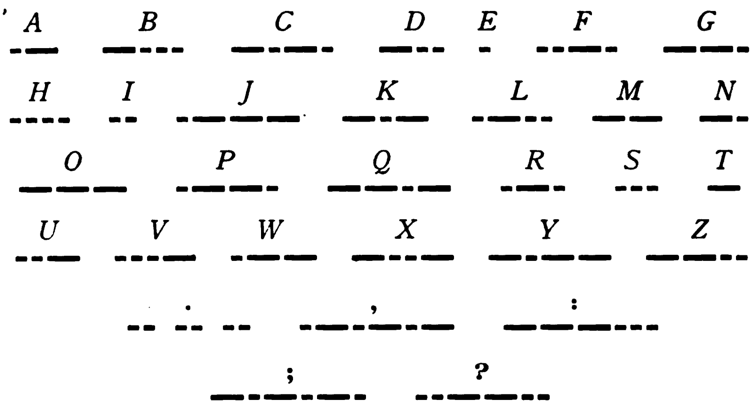
N	*D*	*B*	*8*
—.	—..	—...	—....

When learning the code with the aid of an automatic transmitter, the characters of each lesson should be repeated until they are quickly recognized before the next lesson is taken up. When the sounds can be read correctly, each letter should be written as it is reproduced by the instrument. After the letters can be readily recognized and written down, the learner should practice writing words and short sentences, copying the matter as it is ticked off by the sounder. The speed of transmission should then be gradually increased until it reaches 15 or more words a minute. Automatic transmitting devices are for sale by manufacturers of telegraph instruments.

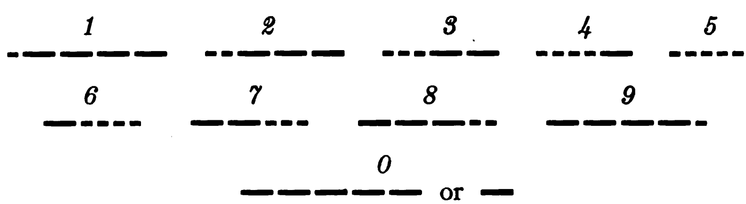
CONTINENTAL CODE

12. Persons desiring to work for submarine-cable companies or for most wireless telegraph companies should learn the **continental, or universal, code,** which is as follows:

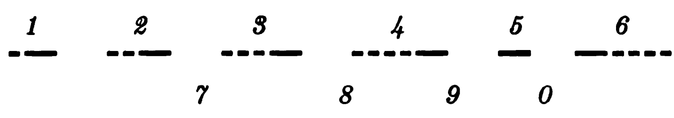
ALPHABET



NUMERALS



The numerals are also made by operators using the Continental code in the following short form:



The Continental code is used all over the world for submarine telegraphy, for land telegraphy in almost every country except the United States, Canada, and parts of Australia, and for wireless telegraphy at almost all ocean-coast stations and on most ocean-going ships. It is much superior to the Morse code for signaling through long submarine cables, and, owing to the fact that it has no spaced letters that are apt to be taken for double letters, it is freer from errors of transmission. For instance, with the Morse code, it is very easy for *ee*

to be taken for an *o*. On a siphon submarine-cable recorder, it would be practically impossible to avoid such errors. The American, or Morse code, owing to the fact that there are fewer dashes in it, is about 5 per cent. more rapid than the Continental. The Continental would doubtless have been adopted in this country if the Morse alphabet had not already obtained such a strong hold on operators. A comparison of the Morse and Continental codes shows that the figure *4* and the letters *a*, *b*, *d*, *e*, *g*, *h*, *i*, *k*, *m*, *n*, *s*, *t*, *u*, *v*, and *w* are the same in both; but the numerals, except the figure *4*, the punctuation marks, and the letters *c*, *f*, *j*, *l*, *o*, *q*, *r*, *x*, *y*, and *z* are different.

13. The Australian colonies (except West Australia and New Zealand, where the Continental code is used) employed a code that was a modification of the Morse. The characters that differed from the Morse were the following: *C* ·——·· for ·· ·; *O* ·—·— for · ·; *R* ··—·— for · ··; and *Z* ———— for ··· ·; *underline*, or *Italics* —···— —···—; *bracket*, or *parenthesis* ·—··· ·—···; *quotation*, ·—·— ·—·— ·—·— ·—·—, altered generally to ·· ·· ·· ··; quotation within a quotation, " ' ' ", ·· ··. The period, interrogation, and exclamation marks, which are the only other punctuation marks in general use in those colonies, are exactly the same as the Morse. With them, the exclamation mark is generally used to express mirth or laughter.

NAVAL CODE

Alphabet

14. The following code, which is sometimes called the United States Navy wireless telegraph code, is used by some naval-vessel operators:

A	*B*	*C*	*D*	*E*	*F*
——	—··—	·—·	———	·—	———·
G	*H*	*I*	*J*	*K*	*L*
——··	·——	·	·———	—·—·	——·
M	*N*	*O*	*P*	*Q*	*R*
————	··	—·	·—·—	·—··	—··

S	*T*	*U*	*V*	*W*	*X*
— · —	—	· · —	· — — —	· · — ·	— · · —

Y	*Z*
· · ·	— — — —

NUMERALS

1	*2*	*3*	*4*	*5*
· · · ·	— — · —	· · · —	— — — ·	· · — —

6	*7*	*8*	*9*	*0*
— — · ·	· — — —	— · · ·	· — — ·	— · · —

SPECIAL WIRELESS SIGNALS

15. The following additional signals are used in wireless telegraphy: *Wait,* · — · · ·; *understand,* · · · — ·; *don't understand,* — · · · · · — ·; *call,* — · — · —; *finish,* · — · — ·; *error,* · — · — · —. Three calls for help are now used in wireless telegraphy: *S O S* is the international danger signal to be used only in times of distress to attract the attention of all stations on sea and land that may be within reach. It is a simple call, consisting, in the Continental code, of three dots, three dashes, and three dots. *C Q D* (come, quick, danger) is the Marconi call for help; and *S 5 S* in American Morse corresponds to *S O S* in continental Morse and is used in America by land stations. The following abbreviations are also used in wireless work: *G E*, good evening; *G N*, good night; *G M*, good morning; *G A*, go ahead; *O S*, ship report; *D H*, dead head, or free message; *M S G*, message; *O P R*, operator; *4*, please start me at; *13*, understand; *25*, am busy now; *30*, no more; *73*, best regards; *77*, message for you; *92*, delivered; *99*, keep out.

TELEGRAPH APPARATUS

DESCRIPTION OF INSTRUMENTS

16. To learn telegraphy, a *telegraph key*, a *sounder*, and a *battery* will be needed for practice. Several grades of instruments, varying in quality and price, are for sale by dealers ir

telegraph instruments. A legless key and sounder, mounted on separate bases, and one or two dry cells make an excellent combination. While it is convenient for a beginner to have the key and sounder mounted upon one base, separately mounted instruments are preferable, because they can be placed in the most suitable and convenient positions on the table, independently of each other.

17. Telegraph Key.—A **telegraph key** is an instrument for opening and closing an electric telegraph circuit; a good key with all the necessary adjustments is shown in Fig. 1. It consists of a nickel-plated steel lever *r* pivoted in trunnion screws *x* and *z*, which are mounted in standards projecting

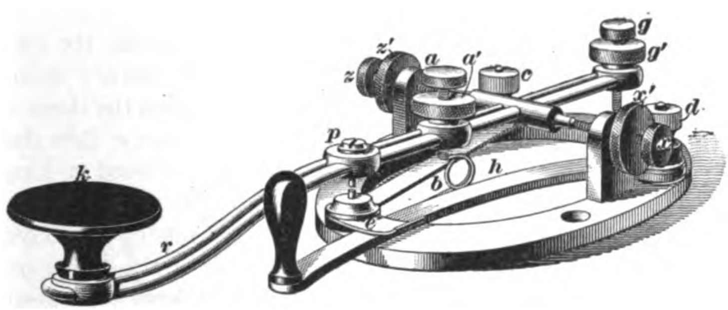


FIG. 1

upwards from a brass base piece. The locknuts x' and z' serve to bind the trunnion screws in any position to which they have been adjusted. A coil spring *b* serves to press upwards the forward end of the lever *r*. The up-and-down movement of the lever, or the *play*, as it is called, is regulated by a screw *g*, which is secured in its proper position by a locknut g'. The upward pressure of the spring *b* on the lever *r* may be regulated to suit the sending operator by means of a screw *a*, which is secured in the desired position by a locknut a'. A screw *p* that passes through the steel lever *r* has on the under side of it a small piece of platinum. When the handle, or button, *k*, which is made of insulating material such as hard rubber, is pressed down, the platinum piece on

the under side of the screw *p* makes contact with a similar piece of platinum projecting upwards from a metal button-like piece of brass. To this brass button is connected a small flat projecting piece of spring metal *e*, which is connected with a binding post *c* by a thin strip of metal. The binding post *c*, the thin metal connecting strip, the piece *e*, the brass button to which the piece *e* is joined, and the platinum tip of the button are all insulated from the base and from all other parts of the key; but the lever *r* is in metallic connection, through the trunnion and its screws *z* and *x* and the spring *b*, with the base and the binding post *d*.

The piece *h* is called the *circuit closer*. Its rear end is pivoted by a screw to the base of the key, so that it makes contact with the binding post *d*. When this closer *h* is turned so as to touch the metal piece *e*, the electric circuit between the two binding posts *d* and *c* is closed, even when the lever *r* is up so as to keep the two platinum points apart. When the closer *h* is open, that is, when it does not touch the piece *e*, then the circuit between the two binding posts *d* and *c* is closed so long as the handle *k* is depressed so as to bring the two platinum points together. The keys on some learners' sets do not have any screws for adjusting the upward pressure of the spring on the lever of the key. The spring on such keys is shaped differently than the one shown in this figure and is carefully adjusted before the instrument is sent out.

18. Telegraph Sounder.—As shown in Fig. 2, a **telegraph sounder** is an electromagnet so constructed that it gives forth sounds that correspond to the up-and-down motions imparted to a key that is connected in the same electric circuit with it. The various parts are mounted on a hollow brass plate, which is, in turn, fastened to a highly polished wooden base. Two coils *m* of fine insulated copper wire surround two soft-iron cylindrical rods, or *cores*, as they are called. A piece of soft iron *n*, called the *armature*, is fastened to a metal lever *l*, and with it forms the *armature lever*. This lever is pivoted between two trunnion screws *v* and *j*, which, when once adjusted, are locked in place by locknuts *v'* and *j'*. The

armature is normally held in its upper position by means of a tensile spring *s* that pulls down on the short end of the lever *l*; the pull of this spring is regulated by a screw *w*. The downward stroke of the lever is limited by the lower end of a screw *i*, which strikes against a piece *u*, called the *anvil;* the upward stroke is limited by the lever striking against the lower end of a screw *o*. The play, that is the up-and-down movement of the armature lever, can be adjusted by means of the screws *i* and *o*, and after the proper adjustment is obtained, it can be made secure by locknuts *i'* and *o'*. One end of the wire form-

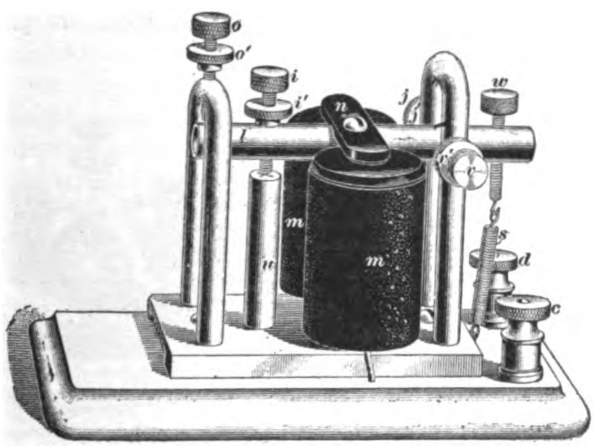


FIG. 2

ing the two coils is permanently fastened to a binding post *c*, and the other end to another binding post *d*.

19. For lines over 1 mile and under 10 miles in length, the sounders should have their magnets wound with more turns of finer wire, and therefore offering a higher resistance to the electric current than those employed on circuits under 1 mile. Such high-resistance sounders are called ***main-line sounders***, and are wound with so much fine wire that their electrical resistance amounts to 20 ohms. Sounders used for short lines have an electrical resistance of 4 or 5 ohms, and are called ***local sounders***. But all telegraph instruments that are

connected in the same line circuit, should always have about the same electrical resistance. More complete descriptions of such sounders and keys as are extensively used by large telegraph and railroad companies will be given in another Section.

20. Combined Sounder and Key.—In Fig. 3 is shown a sounder and key mounted on the same wooden base; this combination is known as a *learner's telegraph set.* The sounder occupies the left-hand, and the key the right-hand, portion. This key and sounder, although differing slightly in some details from the key and sounder already described, are exactly the same in operation. The key and sounder are properly

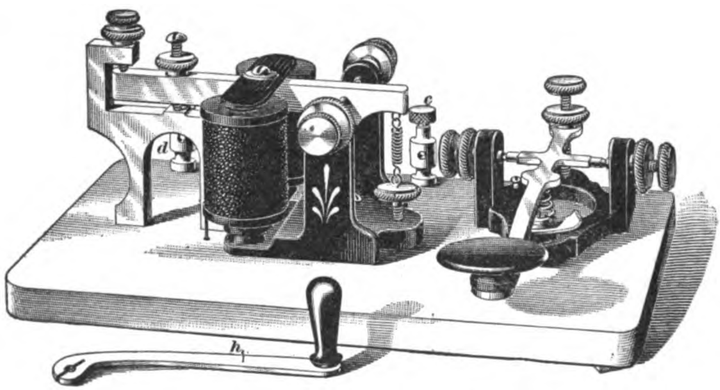


FIG. 3

connected by wires under the base. On the rear of the wooden base are two binding screws *d* and *c*, to which the wires from the battery are connected. The circuit closer *h* is shown detached from the key, as is the case when only a dry battery is used to operate the sounder. When a gravity or other closed-circuit cell is used, the circuit closer is placed in position on the key, as shown in Figs. 1 and 4.

BATTERIES

21. A **cell** is a device for generating an electromotive force by means of chemical action. If the two elements, or terminals of a cell, are joined by a continuous metallic wire, or

circuit, an electric current will flow in one direction through the metallic circuit so long as the circuit remains complete, or closed, provided the electromotive force is maintained by the chemical action. A **battery,** in the strict sense of the word, is a combination of two or more cells, although the two terms are used somewhat indiscriminately.

22. Classification of Cells.—Cells may be roughly divided into two classes: those suitable for furnishing an electric current continuously, and those suitable for supplying current intermittently. The former are called **closed-circuit cells,** and the latter **open-circuit cells.** Closed-circuit cells may be used to supply intermittent currents—that is, they may be used on circuits that are normally open—but open-circuit cells should never be used where a continuous current is required—that is, on circuits that are normally closed. Gravity, Gordon, Edison-Lalande, and bichromate cells are samples of the closed-circuit type; the dry and Leclanché are open-circuit cells. There are many modifications of the Leclanché cell. The circuit may be kept closed all the time when gravity or Gordon cells are used.

The manner of connecting up the apparatus will be the same, no matter what kind of cell is used. For use with one sounder and key, a single cell is generally sufficient; but in case two cells are used, the wire running from one of the binding posts of the sounder, or combination set, is joined to the zinc of the first cell, then the copper of this cell is joined by another wire to the zinc of the second cell, and the copper of the second cell is joined to one binding post of the key, or to the combination set, as the case may be. Two cells so joined are said to be connected in series, and will make the sounder operate about twice as vigorously as one cell.

23. The dry cell is the smallest, cleanest, and cheapest of all cells, but is not very satisfactory, except when but little used, and that intermittently. If this cell is used, the circuit must be kept open at the key at all times except when actually working with the key. To make sure that the cell is not left on a closed circuit, a key should be used from which the

circuit closer can be removed; for, if the circuit closer were left attached to the key, and were closed accidentally or otherwise for any length of time, the dry cell would very soon become exhausted and rendered useless. With the circuit closer removed, the dry cell should last for several months' practice.

24. Setting Up and Care of Cells.—Directions for setting up and caring for a cell are usually sent with it. For a gravity cell, they are usually as follows: After unpacking the cell, wash the copper, zinc, and glass jar. Unfold the copper strip so as to form a cross, and place it in the bottom of the jar. Suspend the zinc in the jar by hooking the catch on the side of the jar. The zinc has a hole and binding post in which to fasten a connecting wire. Put the blue crystals (called *bluestone* or *copper sulphate*), which come with the cell, in the bottom of the jar, distribute them equally between the leaves of the copper, and pour enough water into the jar to cover the zinc. A gravity cell properly set up is shown in Fig. 4.

25. After it has been set up as described and the copper sulphate has been placed in the jar, the battery is put in condition for immediate use by pouring into the jar a solution of zinc sulphate, which is made by dissolving 4 or 5 ounces of zinc sulphate in a little water. This solution should be poured gently so that it will mix as little as possible with the copper-sulphate solution already in the jar. It is a good plan, if there is no great hurry to use the cell, not to put in the zinc until the solutions have had time to settle into their normal conditions. This prevents or reduces the formation of a black deposit on the piece of zinc suspended in the jar.

As it is consumed, bluestone should be dropped into the jar, care being taken that it goes to the bottom and that none of it lodges on the zinc. The need of bluestone is shown by the fading of the blue color, which should be kept at least as high in the solution as the top of the copper, but should never reach the zinc. There should always be some bluestone crystals in the bottom of the jar.

If no zinc sulphate is added in setting up the cell, it will be

necessary to short-circuit the cell, that is, to connect the zinc and copper terminals of the cell with a short piece of copper wire. The cell must be left connected in this manner for some time before it will be in good working condition—24 hours will not be too long, although a shorter time may be sufficient.

26. After the battery has been started, no further attention will be required except to keep it supplied with bluestone

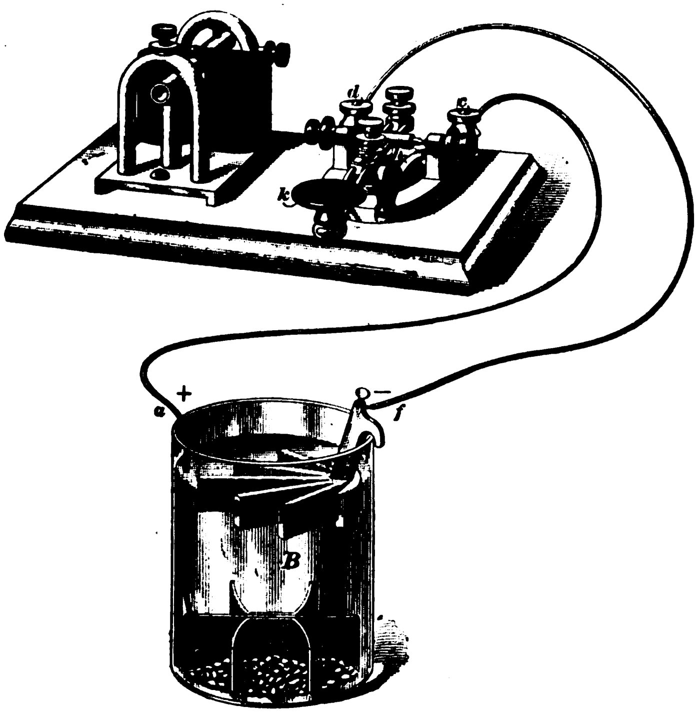


FIG. 4

and water until the quantity of sulphate of zinc in solution has become excessive. During use, the chemical action in the cell causes sulphate of zinc to be formed, and consequently this substance accumulates in solution, the copper sulphate being consumed at the same time. The specific gravity of the zinc sulphate being less than that of the copper sulphate,

the former solution will remain on top. When the zinc sulphate becomes too dense, it will be necessary to draw off a portion of the top of the liquid with a cup or battery syringe and replace the solution removed with clean water. The condition of a cell may be judged from its appearance. When the cell is in good condition the solution in the bottom is a bright-blue color, the blue fading to a water color before reaching the zinc. A very pale or a dirty brown-colored solution indicates a deteriorated condition of the cell. When the zinc becomes coated, it should be taken out, scraped clean, and washed.

A gravity cell can be maintained in excellent condition by keeping it on a closed circuit about half the time; that is, by keeping the circuit closer *h*, Fig. 4, on the key closed about half the time that the key is not being used. For a beginner, who uses the set mostly for practice, this can generally be done without any inconvenience, even if there is another distant set on the same line, by leaving the key and circuit-closer open at night. A Gordon battery may be kept on open or closed circuit, but the more it is kept on open circuit the longer the charging solution and materials will last. This is a clean cell, and requires very little attention. However, the gravity cell is much less expensive, and has proved, all things considered, so satisfactory that it is practically the only primary cell used by all large telegraph companies in this country.

27. Cleaning the Cell.—The whole cell will need to be thoroughly cleaned out occasionally, depending on how much it is used. To do this, remove the zinc, clean it by scraping with a knife or some other edged tool, and wash it with plenty of water. If the cell will not be needed for 24 hours—the time for short-circuiting the cell in order to bring it into working condition—the old solution should be thrown away, the jar cleaned, and a new solution, prepared as already explained, placed in it. If the cell is to be used immediately, the clear liquid should be poured off into a separate jar, the sediment in the cell cleaned out thoroughly, and the solution replaced, enough water being added to cover the zinc. In this way,

the cell will soon be ready for use, and short-circuiting it should bring it into working condition very rapidly.

The connections at the cell terminals should be kept free from dirt and corrosion. The cell will work more vigorously when warm—that is, above 65° or 70° Fahrenheit—than when cold; and under no circumstances should it be allowed to freeze, because, in this case, the current will be much impaired or entirely stopped.

SETTING UP THE APPARATUS

28. Combined Learner's Set.—The combination of a key and a sounder mounted together on one base and properly connected to a gravity cell is shown in Fig. 4. The set should

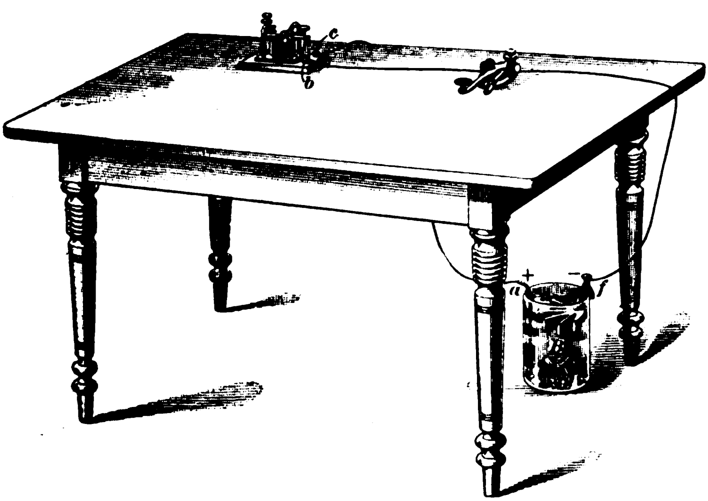


FIG. 5

be firmly fastened on a table far enough back to allow the whole forearm and the elbow to rest on the table. The battery should be placed on the floor under or near the table.

To connect this set, take a piece of copper wire and remove the insulating material for about 1 inch at one end; connect this end to the copper terminal *a* (called the *positive pole*) of the battery *B*; run the wire to the telegraph set on the table,

in order to get the proper length, and cut it off; bare the end and fasten it in the binding post *c*. Then cut off another piece of wire long enough to reach from the telegraph set to the battery; remove the insulating material for 1 inch at each end; fasten one end in the binding post *d* and the other end to the zinc terminal *f* (called the ***negative pole***) of the battery *B*.

29. Separate Sounder and Key.—A sounder and key not mounted on the same base are set up and connected as shown in Fig. 5. The key should be firmly screwed down on a table in a convenient position, and in such a manner that the forearm, including the elbow, may rest on the table. The sounder should also be screwed down to the table in a convenient position to the left of the key. The battery may be placed upon the floor, either under or near the table.

To connect this set, proceed as follows: Remove the insulating covering for 1 inch at the end of the copper wire. Fasten this bared end to the copper terminal *a* (the positive pole) of the battery *B*, and, taking a piece of the wire long enough to reach to the sounder, cut it off, and bare this end as was done at the other end. Then fasten this bared end in the binding post *c* on the base of the sounder. To the other binding post *b* on the base of the sounder fasten the bared end of another piece of wire, and, after cutting off a piece long enough to reach to the key, fasten the bared end in one of the binding posts on the key base. In a similar manner, connect the other binding post on the base of the key with the zinc terminal *f* (the negative pole) of the battery.

30. Trying the Apparatus.—After setting up and connecting the telegraph apparatus, it should be tried to see that it is all right. As a rule, the instruments will be shipped properly adjusted. If a gravity cell is used, it will not work properly as soon as it is set up; so do not readjust the sounder or key to suit such a condition, but short-circuit the battery (by closing the circuit closer *h*, Fig. 4) for from 12 to 24 hours. With a Gordon cell this is not necessary, and under no circumstances should it be done with a dry cell. First open the circuit closer *h* by moving it to the right; if the battery is in

good working condition and the instruments are properly adjusted, depressing the knob *k* of the key should cause the electromagnet of the sounder to draw down the armature lever, producing a clear click; and on releasing the key the armature lever of the sounder should be drawn upwards by the spring, producing another clear click. The first movement, caused by the closing of the electric circuit by depressing the key, is called the *down*, or *forward*, *stroke*, and the latter, caused by the opening of the electric circuit by releasing the key, is called the *up*, or *back*, *stroke* of the sounder.

If the operation of the key does not produce this result after the gravity cell (if this cell is used) has been given time enough to get in good condition, examine all the connections made to see whether all are tight and firm, with none of the insulating covering of the wire intervening between two joined wires or between a wire and a binding post; and whether all binding-post screws are tight. It will also be well to trace out the connecting wires, to be sure that you have connected the proper binding posts together. The apparatus will probably work all right after the above has been done.

31. Adjust the sounder as follows: Place a piece of ordinary writing paper between the iron armature and cores; close the key, thereby closing the circuit and drawing down the armature; adjust the lower-limit screw *i*, Fig. 2, until the paper is held fast between the armature and cores, then readjust this screw and tighten its locknut *i'* until the paper can just be pulled through easily; open the circuit and adjust the upper-limit screw *o* until the lever has a play between the top and the bottom stop-screws of about $\frac{1}{16}$ inch and tighten the locknut *o'*. The spring that draws the lever upwards should be set with just sufficient tension, but no more than is necessary, to raise the lever promptly when no current is flowing through the magnets. To prevent imperfect electrical contact, the points of the key should be kept clean and all binding posts and screws tight.

CIRCUITS

32. To Connect Two Sets.—In order to learn how to receive, the sender and the receiver should be located in different rooms or houses, and they should not communicate with each other except by means of the telegraph. If desirable, more than two telegraph sets may be connected in the same circuit, in which case a person at any one instrument can send, and those at all the other instruments can receive.

Fig. 6 shows two learners' sets connected together. For two instruments that are connected in one circuit and do not require more than about 100 feet of No. 14 iron wire to reach from one set to the other, counting one way only, at least three cells are needed. For a short line, it is convenient to place all the cells at one end, and not some at one end and the rest at the other end. The cells shown here represent Gordon cells.

33. Where two cells are used for this purpose they should be connected exactly as shown. That is, the zinc, or negative terminal *b*, of one cell should be connected to the copper, or positive terminal *a'*, of the other cell, connecting the remaining positive and negative terminals *a* and *b'*, respectively, as though they were the terminals of one and the same cell. Thus, one of these two free terminals *a* should be connected to the binding post *d* of the set in one office *W*, and the other terminal *b'* to the return line, which should be connected to the binding post *f* at the other office *E*. The line wire connects together the binding posts *c* and *e*. In case only one wire is used, the earth being utilized as a return circuit, the return line shown would not be used; instead the terminals *b'* and *f* would be connected to water or gas pipes, as shown by dotted lines.

34. Three Sets in One Circuit.—In Fig. 7, three offices are shown connected to one line circuit. A sounder and a key are placed at each office and three gravity cells at each terminal office. The earth is utilized as a return circuit, and, consequently, only one line wire is necessary. Where more than

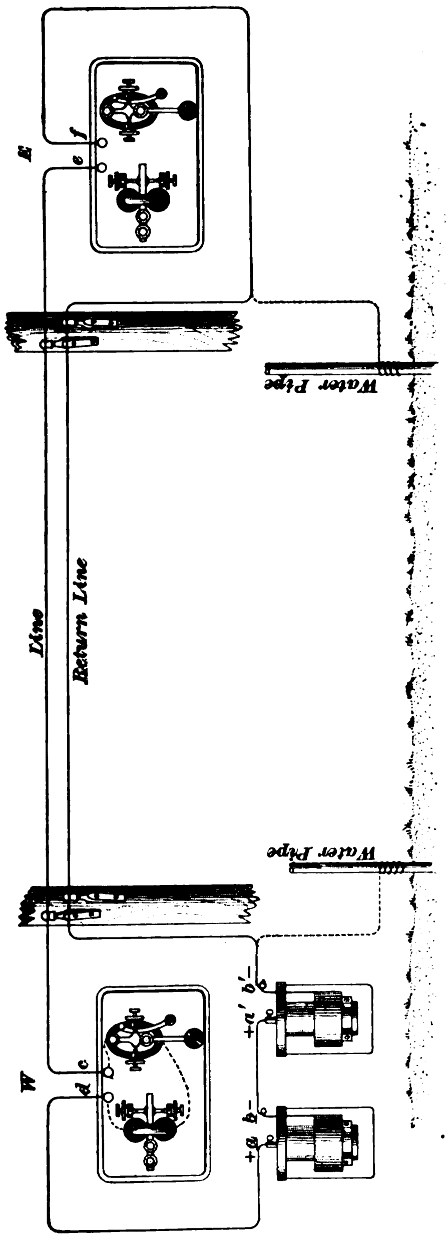


Fig. 6

two instruments are used on the same line, at least one more cell will be required for each additional sounder. For an outdoor line, at least one additional cell will be required for each $\frac{1}{4}$ mile of No. 12 Birmingham wire gauge galvanized-iron wire used. If the line is longer than 1 mile, it will be necessary to add at least three cells for each additional mile.

At one end office *N* the copper terminal of one cell *a* is grounded to a water pipe, the zinc terminal of this cell being connected to the copper terminal of cell *b*. The zinc of cell *b* is connected to the copper of cell *c*, and the zinc of cell *c* to one of the binding posts on the sounder. At the other end, office *S*, one of the binding posts on the key is joined to the copper of cell *d*, the zinc of this cell *d* is joined to the copper

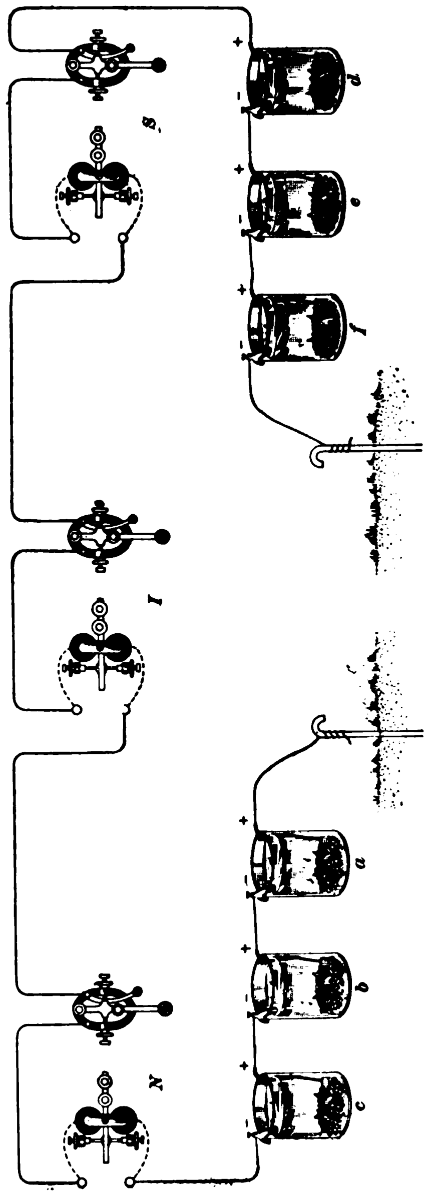


FIG. 7

of cell *e*, the zinc of cell *e* to the copper of cell *f*, and the zinc of cell *f* to the water pipe. The other connections are clear enough to need no further description.

35. When two or more instruments in the same house are to be connected, insulated copper wire, called annunciator, or office, wire may be used. A No. 18 Brown & Sharpe gauge copper wire will be about the right size. Insulated wire may be fastened in place by small staples or double-pointed tacks, care being taken not to cut or injure the insulated covering, and never to fasten two wires under the same tack. The wire must be kept out of contact with water or gas pipes, and all metal work.

36. Joints in an Electric Circuit.—A common way of connecting wires in the United States is shown in Fig. 8. The ends of the two wires should be thoroughly cleaned and

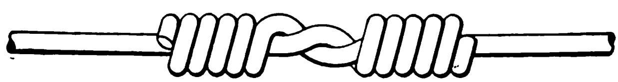


FIG. 8

scraped; and in the case of wires with an insulating covering, the insulation must be carefully removed for about 1¼ inches at each end, without cutting or nicking the wire with the knife used. If nicked, the wire may break very easily. To make the joint, place the bare wires side by side, and then wind each end tightly around the other wire. It is best to solder the joint to insure perfect electrical contact.

37. To prepare it for soldering, the joint may be cleaned with a solution of muriatic acid, in which about as much zinc as possible has been dissolved. This solution is commonly known simply as soldering acid. If the joint is to be covered in any way—with insulating tape, for instance—it should not be soldered with acid, but with resin or some other non-corroding flux. As it is not so easy to make a resin joint as one on which acid is used, the resin joint is held in disfavor by many workers. Acid removes grease from the wire, such as a careless workman may have smeared on from his fingers, but when

the wire is not handled after cleaning, resin will make a good joint. An alternative method is to tin both wires before twisting them together, using acid as a flux; then wipe carefully, cleaning thoroughly to remove all trace of acid, and twist them together as in Fig. 8, using pliers to bend the wire, if necessary. The joint can then be soldered very easily with resin as a flux.

38. When joining the wire to a binding post, the end of the wire should first be made clean and bright, then placed in the hole in the binding post, and firmly fastened there by the screw. Do not allow the bare end of a wire to touch anything except the binding post or another wire to which it is intentionally joined. By wrapping 8 or 10 inches at the end of a wire in a close spiral around a lead pencil, and then sliding out the pencil, a neat springy spiral can be made, by means of which no slack need be left in the wiring, and it will give a nice appearance to the connections.

39. The Earth as a Return Circuit.—It has been known for a long time that, when one pole of a battery is connected with the earth and a wire from the other pole is carried to some distant place and there connected with the earth, a current will flow through the circuit about as readily as if it had been completed by a large wire. That is, the earth is practically one huge conductor. This is easily understood when it is remembered that moisture is more or less present everywhere beneath the surface of the earth and that water is a very fair conductor. All telegraph companies use the earth as a return path for the electric current, thus saving the expense of constructing and maintaining separate return wires for each circuit. But, on short lines, especially indoor lines, it is generally more convenient to run two wires than to make earth connections. Water and gas pipes, on account of their extensive ramifications through the ground, make excellent contact with it, and for this reason make good terminals to which the wire running to ground may be fastened.

40. In case the earth is used as a return circuit, the wires to be grounded should preferably be connected to the same

system of pipes (water pipes are best); that is, if it can be avoided, do not connect at one end to a gas pipe and at the other end to a water pipe. If the wires are grounded by means of a gas pipe, make the connections, if possible, to the pipe on the street side of the meter. For, if this is not done and the meter is not in place or is later removed, the return line will be open. Moreover, the white or red lead used in iron-pipe joints often makes the joints offer considerable resistance to the current before it can reach the ground.

An earth-return circuit may be obtained by connecting the return wires at each end to pieces of sheet copper of about 5 square feet. These copper plates should be placed in a well (never in a cistern) or in a stream of water, or should be buried in soil that is always moist. The joint between the wire and the plate should be a good metallic connection, preferably soldered, and well covered with a moisture or waterproof paint.

41. Outdoor Lines.—For outdoor lines, a suitable and the least expensive wire to use is No. 12 Birmingham wire gauge galvanized-iron or steel wire, which weighs 176 pounds and has an electrical resistance of about 30 ohms to the mile. This bare iron wire must be supported on what are called *insulators*, in such a manner that the bare wire cannot touch any buildings, trees, posts, or any other object except the insulators. If this is not done, more or less of the electric current originating at one end will escape to the earth and return through the earth to the grounded terminal of the battery at the originating end, without having passed through the telegraph apparatus at the distant office.

Insulators are made of glass, porcelain, or hard rubber. The kind to be employed will depend on the position and locality in which they are to be used. What is known as the single petticoat glass insulator will be the kind needed for a short private line. Wooden-pin brackets can be bought, upon which the glass insulators are screwed, the brackets being nailed to supporting poles, trees, or houses, as the case may be. In Fig. 6 the line wires are shown supported on glass insulators and wooden brackets.

OPERATING

SENDING

HANDLING THE KEY

42. Method of Holding Key.—The proper position for holding the key is shown in Fig. 9; it is the one adopted by the majority of the most speedy and perfect operators. Rest the first finger on the top, near the edge, of the key button, with

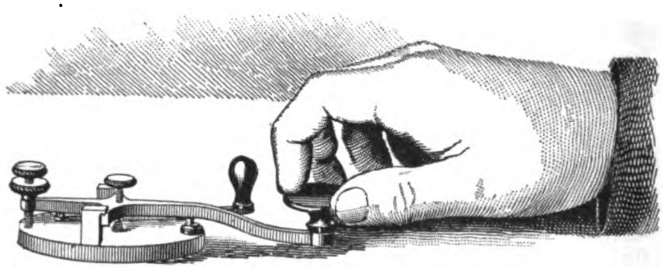


FIG. 9

the thumb and the second finger against the opposite edges, as shown. Curve the first and the second finger so as to form the quarter section of a circle. Avoid straightness or rigidity of these fingers and the thumb. Partly close the third and the fourth fingers. Rest the elbow easily on the table, allowing the wrist to be perfectly limber. When the proper swing is acquired, the forearm moves freely in conjunction with the wrist and fingers. The fingers and thumb should act as the end of a lever, the wrist and forearm doing the work. Let the grasp on the key be moderately firm, but not rigid. Grasping the knob tightly will quickly tire the hand and destroy control of the key, causing what is termed "telegraphers' cramp," or the "glass hand."

43. Avoid too much force or too light a touch, and strive for a medium firm closing of the key. It is not the heavy

pressure of the key but the evenness of the stroke that constitutes good sending. Repeaters can be adjusted for both light and heavy senders, but not for an uneven sender. A repeater adjusted for either a light or a heavy sender would be out of adjustment for a perfect sender. The motion should be directly up and down, avoiding all side pressure. Never, of course, allow the fingers or thumb to leave the key; that is, do not tap or strike the key with the fingers, or allow the elbow to leave the table. The correct method of sending is an easy one, and, when it is properly done, an operator should be able to send for 12 hours continuously without tiring.

44. **Adjustment of Spring of Key.**—In the matter of adjusting the spring of the key, there is considerable difference of opinion. Two of the very fastest senders use very stiff springs, but many other fast senders use springs that are barely strong enough to keep the weight of the key from closing it, and some even use a spring that will not of itself open the key, in which case the thumb must be used to raise the key. A moderate amount of play and a medium tension of the spring should be used by the beginner, unless he has good reason for believing another adjustment more suitable. The spring on the key of the learner's combination set has the right stiffness for the average beginner.

45. **Practice in Sending.**—Begin the use of the key by making dashes in succession, first at the rate of about one a second, and then gradually increasing to two or three. Care should be taken to make the break between the dashes as short as possible, for there is always a tendency to make too large a space between dashes, and this should be guarded against.

The dots should be made as regularly as possible, and at the rate of about five a second, and the speed increased with practice; but, no matter how fast the dots are made, they should be regular, definite, and uniform.

Next attempt the long dash at the rate of one a second, increasing to ninety a minute. Then practice on the following exercises in the order given. In each exercise, after learning to make each character correctly without hesitating, write

them in succession, both forwards and backwards, until able to do so without having to repeat a single character before proceeding to the next.

DASH CHARACTERS

t	*l*	*m*	*5*	*0*
—	⸺	— —	— — —	— — —

46. The tendency to prolong the final dash or dot can be overcome by making it with a movement apparently a little quicker than that used for the preceding dash or dot. In making characters containing a succession of dashes, care must be taken to have them follow one another as closely as possible; too much space is apt to be put between dashes.

DOT CHARACTERS

e	*i*	*s*	*h*	*p*	*6*
·	··	···	····	·····	······

47. Practice each one of these characters until the right number of dots can be made for each one almost unconsciously, being careful at the same time to make all dots of equal duration and not to prolong the last dot into a dash.

DASH-AND-DOT CHARACTERS

n	*d*	*b*	*8*
—·	—··	—···	—····

48. There is a great tendency to make the break between the dash and the dot too long; should this be done, for instance, in making the letter *n*, *te* is made instead of *n*.

DOT-AND-DASH CHARACTERS

a	*u*	*v*	*4*
·—	··—	···—	····—

49. When making each of these characters, let the dots and the dash follow the preceding signal closely, and avoid making the dash too short.

SPACED CHARACTERS

o	*r*	&	*c*	*y*	*z*
· ·	· ··	· ···	·· ·	·· ··	··· ·

50. When making these letters, the space should be made just double that ordinarily allowed between the elements of a letter. Avoid making this space too long, as there is more likelihood that it will be made too long rather than too short. Hold the key down for the duration of 1 dot only; the down-and-up motion of the key is equivalent to another dot; so that the total space is equivalent to 2 dots, or 2 units.

MISCELLANEOUS CHARACTERS

i	*a*	*n*	*s*	*u*	*d*
··	·—	—·	···	··—	—··

h	*v*	*b*	*p*	*4*	*8*
····	···—	—···	·····	····—	—····

51. This exercise shows that, if the last dot in *i*, *s*, *h*, or *p* is carelessly prolonged into a dash, the character following it will be made instead of the one intended. It will be noticed that *a* is the opposite of *n*, *u* the opposite of *d*, *v* the opposite of *b*, and *4* the opposite of *8*. If *a* and *n* are run too closely together, *1* (one) will be made; similarly, too little space between *t* and *h* will produce *8*.

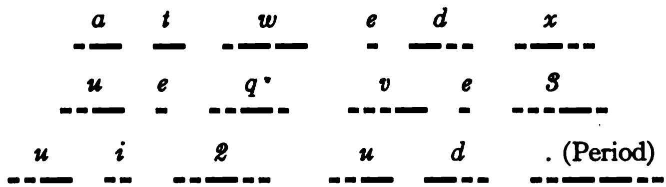
d	*k*	*j*	*g*	*7*
—··	—·—	—·—·	——·	——··

Two of the most difficult characters to make correctly are *k* and *j*. If the final dash in *k* is made too short, *d* will be formed, and if too much space is made before the final dash, *nt* will be formed. Similarly, too much space before the second dash in *j* will transform it into *nn*.

RESULTS OF IMPROPERLY MADE CHARACTERS

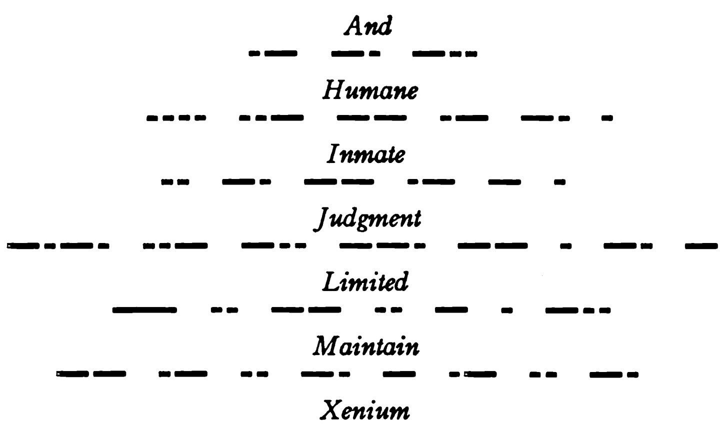
52. In the following lines, the first two characters, improperly connected by too short an interval, will make the third character. Thus, if *a* and *t* are connected by too short an

interval, *w* will be made; and if *e* and *d* are made with too short an interval between them, an *x* will be made, and so on.



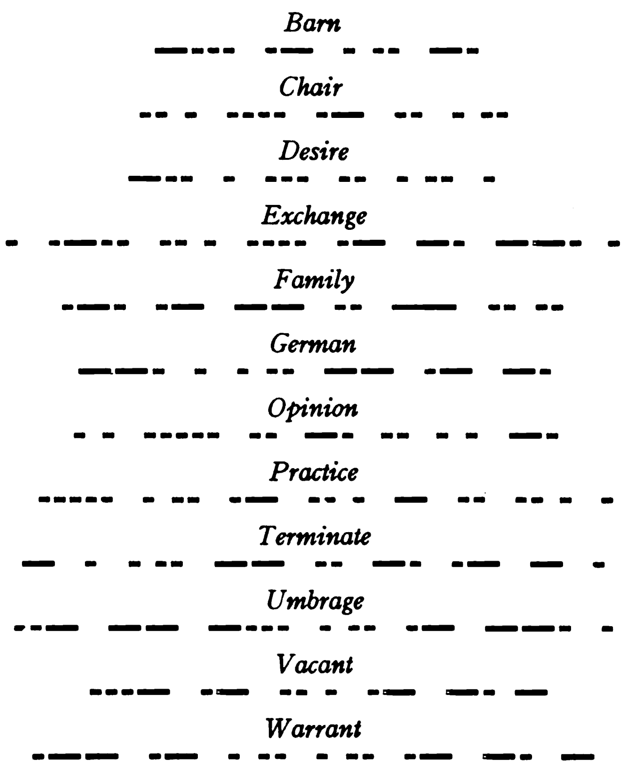
Each of these groups should be repeated until each character in them can be made at will. The beginner should be careful to form each character correctly, because this will lead to a perfect style in sending. There are almost as many styles of sending among operators as there are styles of penmanship. When these groups have been mastered, the transmission of words may next be taken up, followed by the transmission of short sentences, care always being taken to write one correctly before beginning another.

53. Words Not Containing Spaced Letters.—The following words contain no spaced letters, and for that reason are easier to practice upon at the start:



54. Words Containing Spaced Letters.—In words containing spaced letters, examples of which are here given, care

must be taken to make the various spaces in the correct proportion to one another; that is, the space between letters should be three times, and the space in spaced letters two times, the usual space between the parts of a letter as follows:



The following also are good words on which to practice: *Let, little, take, train, jaw, knoll, knot, need, nod, ice, rice, person, poison, Mississippi.* Be careful to make *an, h, i, j, k, p, s,* and *th* correctly, in order to avoid their being taken for other characters, as previously indicated.

55. Accuracy More Desirable Than Speed.—A firm, even, smooth style of sending should be cultivated, and accuracy striven for rather than speed. The practice of timing

for ascertaining the speed of sending should be very sparingly indulged in by the beginner, for it is likely to produce careless habits. The speed of sending should be graduated to suit the capacity of the receiver; the latter should never be crowded. Strictly first-class work will not be required in the first position obtained as an operator, but one must be reliable. High speed is not necessary, and above all things the operator must not be afraid to break, for it is expected of a beginner. He must not imagine that the manager is listening for every break made, for, even if he did, he would forget it much sooner than an error that may be caused by a failure to break. Breaks are soon forgotten, but errors are recorded and are evidence of carelessness that will appear against the operator when an advance in position or salary is expected.

It is well to remember that an operator is no judge of his own Morse, and therefore should not try to see how fast he can send until he has had considerable experience. Fast sending is seldom indulged in by strictly first-class operators, but fast time is made by them on account of their steady, even gait, their perfect characters, and few repetitions or mistakes. The average receiver's opinion in regard to the sending should be accepted before a person decides for himself that his sending is all right, for the poorest operators often think that their sending is good. If the receiver complains that you do not space properly, or calls attention to some particular fault, do not get angry, but take the hint, and try to remedy all weak points.

RECEIVING

56. To learn to receive, it is necessary to have another person manipulate the key, or an automatic sending device produce the characters, for one cannot read by sound from his own writing. It is very desirable that the sender should be able to make the signals distinctly and correctly, otherwise it will be very difficult, if not impossible, for the learner to understand the signals. However, two beginners can get good practice by taking turns at sending and receiving, each

correcting the faults of the other. Persons around a commercial or a railroad telegraph office may practice reading the messages passing over the lines.

There is no change in the tone of a sounder; the letter is determined solely by the time or times the lever strikes the bottom or top stops, and the duration of time between these clicks. The back, or upward, stroke is as necessary in order to read by sound as the forward, or downward, stroke, and these should be distinguished from each other, for the length of time during which the armature remains down could not otherwise be determined.

57. A learner should begin to read by sound by receiving letters and copying them; he should continue this exercise until each letter is instantly recognized. It is not well for a beginner to wait for whole words; each letter should be written down as soon as received, because if he waits for the whole word he is apt to become confused and lose the word, causing him to guess at it. He should learn to listen and write at the same time, and after he is proficient in receiving and writing letters he should practice on words and sentences. The speed of receiving and copying should be gradually increased until both can be done rapidly.

The beginner should thoroughly study the Morse alphabet and memorize it perfectly before making an attempt to copy from a sounder or an automatic transmitting device. Many learners require a longer time than necessary to become fair operators on account of failure to understand and memorize the Morse alphabet.

Open the key whenever a word is not understood and repeat the last word, received. A receiver, and especially a beginner, should not hesitate or be ashamed to ask for a repetition by breaking and telegraphing back the letters *rr* or *rept* (meaning repeat), for it is better to make a large number of breaks with requests to repeat, or for information, than to make one mistake.

58. An operator should learn to copy that which is sent him as far behind transmission as possible. Although this

will be hard to do, especially at the beginning, because it divides the attention and requires the exercise of memory, it must be accomplished before one can become a good receiver of rapid sending. The beginner will find it difficult at first to keep one or two words behind, but by continual practice this can be improved on very much. Expert operators are able to put off writing the first part of a message until receiving the latter part.

When a learner can receive and copy legibly at the rate of about twenty words a minute, he should try to practice on regular lines in some office, which will give him the necessary experience with office work and forms that he can scarcely acquire in any other way. When he is able to receive and copy at the rate of thirty words a minute, he may look for a position as a regular operator. The student should also learn to use the typewriter for copying the messages directly as received from the sounder. The skilful use of the typewriter in receiving is necessary to secure employment as an operator with some companies, especially with the press associations.

GENERAL INFORMATION

59. Office Calls.—Every telegraph office has a call or name, which consists usually of one or two letters; thus, the call for New York is *n y*; Chicago, *ch*; Baltimore, *b*; San Francisco, *s f*. If San Francisco desires to communicate with Philadelphia, the operator repeats the latter call on the line until answered. It is proper to sign one's home office every three or five calls, in order that others on the line may know who is using the wire. The call would be made as follows:

p	*p*	*p*	*s*	*f*
▪▪▪▪▪	▪▪▪▪▪	▪▪▪▪▪	▪▪▪	▪ ▬ ▪
p	*p*	*p*	*s*	*f*
▪▪▪▪▪	▪▪▪▪▪	▪▪▪▪▪	▪▪▪	▪ ▬ ▪

When the Philadelphia operator hears the call, he opens his key and replies by repeating "*i*" several times and signing his own call; thus:

i	*i*	*i*	*p*
▪▪	▪▪	▪▪	▪▪▪▪▪

When answered as above, the San Francisco operator proceeds with his business. The same procedure is followed in the case of any two offices.

60. Common Abbreviations.—To increase the speed of sending telegraph messages, many abbreviations are used. In the following list are given some of the common abbreviations, those most frequently used being given first. Many other abbreviations will be readily acquired in actual business.

Word or Phrase	Symbol	Word or Phrase	Symbol
From	*fm*	Correct, or all right	*o k*
Signature	*sig*	Quick	*qk*
Check	*ck*	Repeat	*rr*
Go ahead	*g a*	Street	*st*
Paid	*pd*	Avenue	*ave*
Collect	*col*	Through	*tru*
Free, or deadhead	*dh*	Address	*ads*
Answer	*ans*	Guaranteed	*gtd*
Hear	*hr*	Business	*biz*
Another	*ahr*	Tariff	*tff*
Charges	*chgs*	Telegraph	*tel*
Message	*msg*	Amount	*amt*
Messenger	*msgr*	Break	*bk*
Operator	*opr*	Express	*ex*
Office	*ofs*	Freight	*frt*
Battery	*bat*	Passenger	*pasgr*
Good morning	*g m*	Before	*b4*
Good night	*g n*	Mistake	*msk*
Immediately	*immy*	Number	*no*
Important	*impt*	No more	*n m*
Minute	*min*	Nothing	*ntg*
Give better address	*g b a*	Instrument	*inst*
Ground wire	*g w*	Morning	*mng*
Please	*pls*	Train	*trn*
Superintendent	*supt*	Manager	*mgr*
Conductor	*condr*	Way bill	*w b*
Engineer	*engr*	Circuit	*ckt*
Wait a minute	*1*	Do you understand?	*13*
Where shall I go ahead?	*4*	The end, or finis	*30*
What is the matter?	*18*	Are you ready?	*77*
Accept my compliments	*73*	Who is at the key?	*134*

61. Office, or Service, Code.—The Postal Telegraph Company uses, in addition to the usual abbreviations, a

so-called code for office, or service, messages. The code is simple, consisting of words, initial letters, and combinations of letters representing phrases that are used frequently. By this means operators are relieved of considerable work both in sending and in receiving. The service code is as follows:

CODE WORD	MEANING	EXAMPLE
CANCEL	Cancel and file.	Our H 41 New York, Henry Briggs, signed Hooper, CANCEL.
COLLECT	Collect there. Payment refused.	Your A 216 Chicago, Weld & Son, signed Paterson, COLLECT.
COLUNK	Collect there. Addressee unknown.	Your A 219 Buffalo, Henry W. Gerrish, 21 Monmouth St., East Boston, signed Gerrish & Co., COLUNK.
DELD	Delivered O. K.	Your A 117 of 31st, John C. Wilson, DELD.
D F S	Disregard former service.	
DUP	Duplicate quickly from original, word not understood.	Your G 91 Armour & Co., tenth Abhor, DUP.
G B A	Give better address. Unknown at address given. Not in directory.	Your A 94 N. Y., Wm. Newcomb, 31 Broad St., signed G. J. Foss, G B A.
H A	Hurry answer.	Our A 83 Price, McCormick, signed Jones & Co., H A.
H C	Hurry press check.	Transcript 30th, H C.
MISSING	Missing number. Describe.	Your C 16, MISSING.
NOFTRAF	No office this line. We transfer and turn in tolls as uncollectable.	Your F 32 John Peters, Austin, N. Y., signed Fleming, NOFTRAF.
ORNORD	Original not received. Have delivered duplicate with explanation. Please trace.	Your C 90 Chicago, Swift & Co., Boston, signed Swift, ORNORD.
LOCKED	Place closed. Will deliver soon as open.	Your A 94 Hartford, Horace Conkling, signed F. H. French, LOCKED. (*This message to be sent only when the place is closed for some unusual cause.*)

Code Word	Meaning	Example
R F O	Repeat from original. Message not understood.	Your 204 Boston G. F. Smith, signed Henry, R F O.
S O S	See our service.	
S Y S	See your service.	
Transfer	Transfer there and instruct us to cancel.	Your 46 Elmira, John G. Fitch, San Antonio, signed Reynolds, Transfer.
Undeld	Undelivered. Addressee has left.	Your B 38 St. Louis, F. H. Webster, signed James, Undeld.

MESSAGES

62. Commercial Messages.—A **commercial message** may be divided into eight parts, as follows: the number of the message, the office call, the operator's personal signal, the check, the place from and the date, address, body, and signature. In giving examples of messages, the following plan will be followed: All parts of a message that are both transmitted and copied will appear in *Italic;* all parts transmitted but not copied will be enclosed in parenthesis ( ); all parts written by the receiving operator but not transmitted will be enclosed in brackets [ ]; and finally all parts appearing on the original and final message but not transmitted will be in SMALL CAPITALS

63. Check of Messages.—A complete **check** of a message consists of the following parts in the order given: The abbreviation *hr* (hear), *city* or *tru* (through), the abbreviation *No* followed by the number of the message for that day, the sending-office call, the sending operator's private sign, the receiving operator's private sign (the latter appears only on the received message blank), the abbreviation *ck* (check), the number of words charged for, and finally the word *collect* or *free*, if the message is not prepaid. Formerly the word *paid* was sent if the message was paid for by the sender, but in order to save time and labor it is now considered unnecessary; if the word collect or free is not transmitted, the receiving operator understands that the message is paid for.

Sometimes *ahr* (another) is used in place of *hr*, and if the message is free, the reason is generally given. It is considered a waste of time and labor to send *hr* when a number of messages are being transmitted over the same circuit one after the other. In some systems, the operator's private sign is very seldom, if ever, sent. Stating the number of words charged for aids in preventing errors and omissions. In messages sent collect, the word *collect* is counted but not charged for. The check should read *11 collect*, for a collect message containing 10 words in the body of the message.

The complete check for an ordinary 10-word paid message, sent from Scranton direct to some office and not relayed (that is, retransmitted), is as follows:

(Hr city No) *35 scr sn* [hs] (ck) *10* [paid]

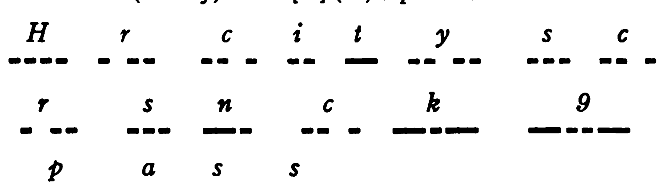
If the message is for some place other than that to which it is sent, and hence has to be relayed, and if collect instead of paid, it is as follows:

(Hr tru No) *35 scr sn* [hs] (ck) *11 collect*

64. The symbol *hr* is the signal that precedes each message; *city* means that the message is for some one at the point to which it is sent; *tru* means that the message has to be sent through to some other office; *scr* is the sending-office call; *sn*, the sending operator's private sign; and *hs*, the receiving operator's private sign. The symbol *hs* is not transmitted, but is written on the telegram by the receiving operator.

When a message is sent free on account of a pass, the number of the pass is not sent; but, if free on an operator's account, *opr* is sent, preceded by the abbreviation *dh* for deadhead. The check for such a message containing 9 words is as follows:

(Hr city) *scr sn* [hs] (ck) *9 pass* No 225



But, if sent on an operator's account, it would be sent thus:

(Hr city) *scr sn* [hs] (ck) *9 dh opr*

h	*r*	*c*	*i*	*t*	*y*	*s*	*c*
· · · ·	· · ·	· · ·	· ·	—	· · · ·	· · ·	· · ·

r	*s*	*n*	*c*	*k*	*9*
· · ·	· · ·	— ·	· · ·	— · —	— · · —

d	*h*	*o*	*p*	*r*
— · ·	· · · ·	· ·	· · · · ·	· · ·

65. Date of Messages.—The **date** of a message consists of the name of the place where the message originates, the month, the day of the month, and the year. The month and the year are always omitted in actual transmission. Sometimes the office call is given instead of the name of the place; but when the message goes beyond the line on which it originates, and in all commercial business, the name of the place must be sent. The name is often abbreviated, but it is better to spell it out in full, especially if the abbreviation is not well known and can be mistaken for some other place. The sending operator always prefixes the word *from*, abbreviated to *fm*, or *fr*, before the date, but the receiving operator never writes this. No periods are transmitted after abbreviations.

66. Address of Messages.—The **address** on a message should consist of the full name and address of the person to whom the message is sent. The name of the street, if it is a number, as Third Street, should be spelled out and not written as a numeral. When an office at which a message terminates is on the same line as the sending office, the name of the place is not sent, only the office call being given; when, however, the message is to be relayed, the destination is spelled out in full. The address is always preceded by the word *to*, and a period follows the address, thus separating it from the body of the message. The receiving operator never writes the word *to* before the address. Except at the end of the address, that is, before the body of the message, the period is seldom used. The comma is used in place of the period at the end of sentences, and the comma, as ordinarily used, is not transmitted.

67. Body of Message.—The body of a message is embraced between the end of the address and the signature.

No abbreviations are permitted, or, if inserted, each abbreviation is considered as a word. Numbers should be spelled out in full, and if the figures also are inserted, they too are counted. The body of some messages is composed of combinations of figures, letters, and disjointed words—words often not to be found in any dictionary. Such messages have no meaning or sense until interpreted by means of a key in the possession of sender and receiver, and are either code or cipher messages; messages of this class are considered elsewhere.

68. Signature.—The **signature** of the sender is preceded by the abbreviation *sig* without a period; in fact, periods are seldom if ever sent after abbreviations or initials in any part of an ordinary message. When there are several signatures, only the last one goes free. The receiving operator never copies down the abbreviation *sig*. The time the message is received should be placed under the signature in a typewritten message, or on the same line with the check or immediately above it in a message written with a pen.

69. Complete Message.—The following complete message shows all its parts—those that are transmitted by the sending operator but not copied by the receiving operator, and those that are not transmitted but are written in. The parts that are transmitted but not copied are indicated, as already explained, by enclosing them in parentheses ( ); the parts that are not transmitted but written in are indicated by enclosing them in brackets [ ], except in the case of the name of the month, which is given in small capitals. The month appears on the original as well as the completed copy, but it is never transmitted. The part of the message that is both transmitted and copied is given in Italic type.

(Hr city No) *35 scr sn* [hs] (ck) *10 collect*

(Fm) *Scranton* SEPT *12* 1911

(To) *W S Henry*

2611 Eden Ave

New York.

Instruction papers on telegraphy were mailed on the fourth

(Sig) *John Doe*

[6:45 P. M.]

H r c i t y N o 3

5 s c r s n c k

9 c o l l e c t

F m S c r a n t

o n 1 2

T o W S H e n r

y 2 6 1 1 E

d e n A v e N e w

Y o r k .

I n s t r u c t i o

n p a p e r s o n

t e l e g r a p h

y w e r e m a i l

e d o n t h e f o

u r t h

S i g

J o h n D o e

Form No. 1.

THE UNITED STATES TELEGRAPH COMPANY.

This company **TRANSMITS** and **DELIVERS** messages only on conditions limiting its liability, which have been assented to by the sender of the following message.

Errors can be guarded against only by repeating a message back to the sending station for comparison, and the company will not hold itself liable for errors or delays in transmission or delivery of **Unrepeated Messages**, beyond the amount of tolls paid thereon, nor in any case where the claim is not presented in writing within sixty days after the message is filed with the company for transmission.

This is an **UNREPEATED MESSAGE**, and is delivered by request of the sender, under the conditions named above.

JOHN DOE, President and General Manager.

NUMBER	SENT BY	REC'D BY	CHECK

RECEIVED at 632 WYOMING AVE., SCRANTON, PA. ____________ **19**

Dated ____________

To ____________

Fig. 10

The ordinary blank forms used by the different telegraph companies for unrepeated messages vary so slightly that the one shown in Fig. 10 may be said to be typical of all receiving blanks. On the sending blanks are spaces for the receiver's No. or counter No., the time filed, and the check.

70. A message sent from Scranton to Columbus that must be relayed, say at Buffalo, would be received at Buffalo as follows:

(Hr tru No) *35 scr sn* [hs] (ck) *12* [paid] *Dely chgs gtd*
(To) *W S Henry* (Fm) *Scranton* SEPT *12* 1912
2611 Eden Ave
Columbus.
Instruction papers on telegraphy were mailed on the fourth as you requested
(Sig) *John Doe*
[6:55 P. M.]

Dely chgs gtd means "delivery charges guaranteed."

The copy received at Columbus would be:

(Hr city No) *37 scr sn* [px] (ck) *12* [paid] *Dely chgs gtd*
(To) *W S Henry* (Fm) *Scranton* SEPT *12* 1912
2611 Eden Ave
Columbus.
Instruction papers on telegraphy were mailed on the fourth as you requested
(Sig) *John Doe*
[7:10 P. M.]

Suppose that W. S. Henry, 2611 Eden Avenue, New York, to whom the following telegram was sent by John Doe, from Scranton, had left New York before the message was delivered, but had left orders for his telegrams to be forwarded to him to Youngs Hotel, Boston, and also that this message was collect, the rate to New York being 25 cents and from New York to Boston 33 cents. The message, beginning with the (ck), as forwarded from New York to Boston, would be as follows:

(ck) *15 collect 33 c & 25 c 4 ex w*
(To) *W S Henry* (Fm) *Scranton Pa* SEPT *12 via New York Sept 12*
Youngs Hotel
Boston.
Have all instruction papers on telegraphy reached you wire answer
(Sig) *John Doe*
[7:45 P. M.]

The four extra words (4 ex w) are "Scranton Pa 12" and the word "collect" included in the check, making 15 words, only 14 to be charged for, however. Experience in an office is almost indispensable before all rules for checks and message forms can be thoroughly understood.

71. Address Incomplete or Incorrect.—If the address of the message from Scranton to W. S. Henry, New York, were received in such a shape that the party could not be located, New York would telegraph back the following:

(To) *Scranton*
g b a [give better address] *your No 35 of twelfth Henry sig Doe*
(Sig) *New York*

Scranton might reply to this message:

(To) *New York*
Cant [cannot] *g b a our No 35 of twelfth Henry sig Doe*
(Sig) *Scranton*

72. Through Receiving.—On most systems an operator should always say *O K* and sign his own private letters or mark, as shown below, when he has finished receiving a message or a number of messages.

O *K* *S* *n*

If no *O K* is received it will be known that the message has not been properly received, and must be repeated.

73. Repeated Messages.—In order to avoid mistakes or delays, the sender of a message may have it *repeated*, that is, telegraphed back to the originating office for comparison. There is an extra charge usually of one-half the regular rate for repeating a message, and the words *repetition* and *paid*, which must be inserted immediately after the signature, are also charged for. Extreme care must be taken by all operators in receiving, and especially in sending repeated messages.

74. Mistakes in Receiving and in Sending.—An operator, after receiving a message, should be careful that he has the correct number of words called for by the check sent with

the message. If they do not agree, the error should be found by comparing with the sending operator. To do this, it is customary to begin at the period, and to write the first letter in each word until the missing portion is found. If the sending operator perceives that he has made a letter incorrectly, he stops, makes seven or more dots, says *msk* (mistake), and begins again with the last word he made correctly.

75. Suppose that, in sending the first message given, the sending operator at Scranton failed to send the word "mailed," or that the receiving operator at New York neglected to copy it. The New York operator would see by the check that the message consisted of 9 words and that he had but 8. He would signal back *8 w*, signifying that he had only 8 words instead of 9. The Scranton operator would count the words again, and if he found there were 9, as before, he would signal *9 collect*, and immediately signal the first letter of each word in the body of the message. This is termed *lettering* the message. He would transmit . (period) *i p o t w m o t f*. The New York operator would signal back *ga* (go ahead) *fifth*, which would be the word immediately preceding the missing one. The Scranton operator would then signal the words *were mailed*, and the missing word *mailed* would be discovered.

Suppose that the 12-word message from Scranton passed through Buffalo and reached Columbus with only 10 instead of 12 words. The Columbus operator, on discovering the discrepancy, would signal back to Buffalo *10 w no exa*. The Buffalo operator would look over his message, and, finding in his copy but 10 words, would signal to Columbus *bk hold it, I will get fixed*. The Buffalo operator would then signal to Scranton to get his No. 37. When the Scranton operator had found his No. 37, Buffalo would signal *10 w no exa*. The Scranton operator would locate the error and send the missing words to Buffalo. The Buffalo operator, after correcting his own copy, would proceed to help the Columbus operator to correct his copy.

76. An operator should never begin to transmit a word until he knows what it is. A receiver dislikes very much to

spoil his copy by having to alter or erase a word. A clue to an obscure word will usually be given by the sense of the message, which can be obtained by reading the whole message through. The wire must not be held any longer than is really necessary, nor should the chief operator be consulted until the sender has done his very best to decipher the doubtful word. When an omission in copy is indicated by asterisks (*), repeating the letter *x* for each one will indicate them.

When the receiving operator finds that he is not getting a message correctly, he breaks, that is, opens the circuit, and telegraphs back *g a*, followed by the last word correctly received; the sender should immediately resume his message, beginning with the word indicated by the receiver. If the receiver wants the entire message repeated he should signal *rr* or *rept* (repeat).

77. Counting Words in Ordinary Message.—On regular full-paid business, the charge for any number of words up to 10, inclusive, is the same, but for all over 10 words, an additional rate per word is charged. The words to be counted include all those in the body of the message, all signatures—except the last one, if several are signed—and all titles and directions after the signature; except that such titles as president, manager, chief police, general superintendent, etc., not exceeding two words, immediately preceding or following the signature, go free.

There is a tendency, in order to shorten telegrams, to use unauthorized compounds of two or more words; therefore, in counting the words in a message in any language, the test of each one is whether it is given in a reliable dictionary of that language as a one-word form. For example, *never-to-be-forgotten* may be used in the English language and *Glückwunsch* in the German language. As the expression *never-to-be-forgotten* is not found in a dictionary as one word, it would be counted as four words; but though the term *Glückwunsch* is made up of two distinct words, *Glück* and *wunsch*, the one-word form is authorized by German dictionaries and would therefore be counted as one word. Such unauthorized compounds as *canbe*, *dothe*, *allright*, etc. would each be counted as

two words. The term *per cent.*, however, is counted as one word whether written as a solid word or as two words. Such words as *anywhere*, *railroad*, etc. are simple English words and are counted as such; so, also, are words like *tonight*, *tomorrow*, etc., unless the customer insists on having a hyphen inserted, in which case two words are charged for.

78. The name of a state, territory, province, city, town, or village is counted as one word, even when it consists of two or more parts, as *New York*, *District of Columbia*, *Nova Scotia*, *East St. Louis*. Each part of the name of a country or county, however, as *Great Britain*, is counted as a separate word.

Each part of the name of a person appearing in the body of a message, as *W. H. Brown, Jr.*, is counted as a separate word, except that the surname, if made up of two parts, as *Van Dorne*, is counted as one word.

Initial letters, as *G. W. E. A.*, and nearly all abbreviations, as *lb.* for pound or pounds, are counted the same as if spelled out in full. Exceptions to this rule are the abbreviations *A. M.*, *P. M.*, *F. O. B.* or *fob*, *C. I. F.* or *cif*, *C. F. I.* or *cfi*, *C. A. F.* or *caf*, and *O. K.* In these cases the term represented by the abbreviations is counted as a single word.

To prevent liability of error, numbers and amounts should be written in words; if the customer refuses to do so at the request of the receiving clerk, each figure will be counted as a separate word. Thus, if a number, as *ten millions*, is written in words, it will be counted as two words, and if it is written in figures, as *10 000 000*, eight words will be charged for. Each decimal point or bar of division used to express a fractional part of a number written in figures, as *47.75* or *47¾*, is charged for as a separate word.

When an ordinal number, as *first*, *second*, *third*, *fourth*, is expressed by a numeral and the suffix of the ordinal number, as *1st*, the suffixes *st*, *d*, *nd*, *rd*, and *th* are each counted as a separate word. Thus in a street address written *No. 185 West 23rd St.*, nine words would be charged for; the periods after the abbreviations not being transmitted nor counted. When

intended for transmission each mark of punctuation is charged for as a word.

79. Counting Words in Code and Cipher Messages. In code and cipher messages consisting of combinations of words, letters, figures, and punctuation marks, each word, letter, figure, and punctuation mark must be transmitted exactly as written by the sender. All groups of five letters or less, when they do not form dictionary words or are not contained in standard code books, such as the Western Union Telegraph Company's code book, which contains over 175,000 words and phrases, the Postal Telegraph-Cable Company's code book, the A B C code book, Lieber's Telegraphic Cipher Code book, and the Commerce Code book, are each counted as a word. When the groups consist of more than five letters, the letters are counted at the rate of five to a word, the letters in excess of five or some multiple of five being counted as a word. Thus, *cadb* and *daceb* would each be counted as a word, and *fedgbac* and *likgabejecd* would be counted, respectively, as two and three words.

When groups of letters form dictionary words, each such group will be counted as one word; thus, *excursion* would be counted as one word, and *itis* would be counted as two words; when a group consists of letters, figures, and marks of punctuation, as *A1*, *43B628*, *3—D; 9*, each letter, figure, and mark of punctuation is counted as a separate word; these latter directions apply to the ordinary as well as code messages.

80. The following is an example of a code message and illustrates the preceding directions for counting words, the number in each group being indicated by the figure under it, the total number of words charged for being fourteen.

(No) *35 scr sn* [hs] (ck) *14* [paid] *cipher*
(To) *W S Henry* (Fm) *Scranton* SEPT *12* 1912
2611 Eden Ave
New York.

Turtle		*4643*		*adcbrbm;*		*particulars*		*712C3*	
(1)	+	(4)	+	(2) + (1)	+	(1)	+	(5)	= 14

(Sig) *General Manager John Doe*

[7:30 P. M.]

In this message the word *cipher* is sent immediately after the full check, and before the abbreviation *fm*.

In code messages on some cable lines, dictionary words not exceeding fifteen letters, strictly pronounceable groups of not more than ten letters, unpronounceable groups of not more than five letters, and groups of not more than five figures are each counted as one word.

81. Charge for Messages.—In case several copies of the same message are made and delivered to different persons, each copy must be paid for. To calculate the full charge for a message that goes to an office on the line of another telegraph company, determine the rate to the transfer office, and to this add the rate between the transfer office and the place of destination. A message must be all prepaid or all collect when it is transmitted over two or more lines. Pay in advance is generally required from all except responsible customers for both a message and an answer.

82. Night and Reduced-Rate Messages.—Night messages, which are sent at reduced rates, may be handed in at any time. They are usually transmitted during the evening or during any slack time, but must never be delivered until the next morning. These messages are copied on blanks printed in red ink, and the sending operator sends the word *red* before the number, and the words *night rate* immediately after the check.

Government messages have priority over other business, and are sent at reduced rates. Press messages are also sent at reduced rates. Such messages as government and press despatches, which require especially quick service, are called "pink" messages, because such messages are copied at relay offices upon pink blanks and the word *pink* is written before the abbreviation No on the message blank and is transmitted before the number of the message.

83. Night letters are accepted by telegraph companies not later than midnight for delivery the next morning at the rate of fifty words or less at the standard day rate for ten words, and each additional ten words or less at one-fifth of

such standard day rate for ten words. At the option of the telegraph company night letters may be mailed (postage prepaid) at destination to the addressee. Night letters must be written in plain English—code language is not permitted.

84. Day letters containing fifty words or less are sent by telegraph at one and one-half the rate charged for night letters, each additional ten words or less in the day letter being charged for at one-fifth the initial rate for such fifty words. A day letter may be forwarded as deferred service and the transmission and delivery of such day letter is subordinate to the priority of transmission and delivery of regular day messages. The telegraph company does not agree to deliver a day message on the day received unless there is sufficient time for transmission and delivery during regular office hours subject to the priority of transmission of regular day messages. Day letters must be written in plain English—code language is not permitted—and may be delivered by telephoning the same to the addressee.

85. Recording of Time of Filing Messages.—The action of several states requiring telegraph companies to place the time of filing on all messages makes interesting the system used in England for transmitting this filing time on messages. Following is a list of letters and an explanation of the code used by the English government service. The hours from 1 o'clock to 12 o'clock—both day and night—are denoted by the first twelve letters of the alphabet (*J* being omitted), thus:

A denotes 1 A. M. or P. M.	*G* denotes 7 A. M. or P. M.
B denotes 2 A. M. or P. M.	*H* denotes 8 A. M. or P. M.
C denotes 3 A. M. or P. M.	*I* denotes 9 A. M. or P. M.
D denotes 4 A. M. or P. M.	*K* denotes 10 A. M. or P. M.
E denotes 5 A. M. or P. M.	*L* denotes 11 A. M. or P. M.
F denotes 6 A. M. or P. M.	*M* denotes 12 A. M. or P. M.

86. The fact that *M* is the initial letter of midnight and midday will enable one to remember that *M* is the code letter for 12 o'clock. The twelve letters denote not only the 12 hours but the twelve periods of 5 minutes each of which each hour is

composed. Thus, *A* denotes 1 o'clock and also a period of 5 minutes; *B* denotes 2 o'clock and a period of 10 minutes; *F* denotes 6 o'clock and a period of 30 minutes. If the letters are used singly they show the hours only. If used in combination, they show the hours and some number of periods of 5 minutes each in addition to the hour. Thus, *M* by itself denotes 12 hours, and *M A* denotes 12 hours and 5 minutes; *A* by itself denotes 1 hour, and *A A* denotes 1 hour and 5 minutes; *C* by itself denotes 3 hours, and *C H* denotes 3 hours and 40 minutes.

In order to denote the 4 intermediate minutes in every complete period of 5 minutes, the letters *R*, *S*, *W*, *X* are employed, *R* denoting the first, *S* the second, *W* the third, and *X* the fourth minute after each hour or after each complete period of 5 minutes. Thus, *M R* denotes 12 hours and 1 minute, or 1 minute past 12 o'clock; *M S* denotes 12 hours and 2 minutes, or 2 minutes past 12 o'clock; *M W* denotes 12 hours and 3 minutes, or 3 minutes past 12 o'clock; and *M X* denotes 12 hours and 4 minutes, or 4 minutes past 12 o'clock. So, again, *M A R* denotes 12 hours and 6 minutes, or 6 minutes past 12 o'clock; *F F S* means 6 hours and 32 minutes, or 32 minutes past 6 o'clock; and so on. At 1 P. M. exactly the code becomes *A*, and it remains *A* until a complete minute has expired; that is, until 1 minute past 1 o'clock, when it becomes *A R*.

87. The cable companies use the 24-hour clock system instead of the 12-hour clock system. In the 24-hour clock system, the hours from noon to midnight are designated by letters as follows:

N denotes 1 P. M.	*T* denotes 7 P. M.
O denotes 2 P. M.	*V* denotes 8 P. M.
P denotes 3 P. M.	*W* denotes 9 P. M.
Q denotes 4 P. M.	*X* denotes 10 P. M.
R denotes 5 P. M.	*Y* denotes 11 P. M.
S denotes 6 P. M.	*Z* denotes Midnight

The letters designating the hours before noon, 5-minute and 1-minute periods in the 24-hour clock system remain

the same as in the 12-hour clock system. Thus, *N A R* denotes 1:06 P. M., and *V E X* denotes 8:29 P. M. The 24-hour clock system is used generally by cable companies throughout the world, although the filing time does not appear on the messages as delivered to customers.

88. Company Business.—Between employes and on company business, no checks are sent with a message, and much less formality is necessary than with commercial business. Messages that are used to assist in the prompt transaction of business and for the correction of errors are called *service*, or *office*, *messages*.

89. Privacy of Messages.—No information of any kind respecting messages should be given to any one other than the party to whom the message is addressed. A person that wilfully divulges the contents or the nature of such contents may be punished, if convicted, by a fine of not more than $1,000, or by imprisonment for not more than 6 months, or by both such fine and imprisonment.

The Western Union Telegraph Company has the following rule on this subject: "Any officer, clerk, operator, or other employe handling messages, who shall report or divulge the contents of such messages to any officer of the company, or other person, shall be promptly dismissed from the service of the company, and prosecuted under the law making it a penal offense to divulge the contents of messages."

90. Courtesy of Clerks.—In small offices where the operator also acts as receiving clerk at the window, he should aim to be courteous and helpful to those sending telegrams. For instance, if an individual, evidently not accustomed to sending telegrams, seems to be having trouble in writing the message, the clerk may render an appreciated service, and help make telegraphing more popular by saying, "Shall I help you to write your telegram?" Often the customer finds it difficult to reduce the message to a 10- or 15-word telegram, and is on the point of tearing up the message when he learns the cost, with the intention of sending it by mail, instead. In such cases, the clerk should suggest to the customer, as he

generally can, a way to cut or rewrite the message, thus reducing the number of words without destroying its sense. Many messages can thus be saved to the telegraph company, and, moreover, the customer will generally thank such a polite and obliging operator, and will use telegrams oftener. In this manner, and in every other way possible, the clerk or operator should strive to increase the business of the company.

91. Railroad Business.—Much less formality is necessary in conducting railroad business than in transmitting commercial messages. The names in addresses and signatures are sometimes abbreviated to the initials only. No checks are sent, the entire date is also omitted, and many words in the body of the message are abbreviated. Instead of spelling out the name of the place, usually only the office call is given. When, however, the business over one railroad line passes to the line of another company, it is transmitted the same as any other free or paid message.

In despatching trains, many prescribed forms are in use, in order to economize time. Each road usually gives positive directions regarding the use of every train-order form. These directions are usually embodied in a set of rules, which the men may study and learn at their leisure, thus avoiding the necessity of repeating such direction in the body of each order.

ABBREVIATED AND CIPHER SYSTEMS

92. Phillips's Code of Abbreviations.—Mr. W. P. Phillips's code is a system of abbreviations, or a sort of shorthand applied to telegraphy. It consists of single letters and combinations of two or more letters, which arbitrarily represent figures, words, and whole phrases. The Morse code is used for all letters and figures, but not for all the punctuations. Words and phrases that occur most frequently in newspaper reporting are represented by single letters and short combinations of letters; for example,

C j means *coroner's jury*
A b m n means *abomination*
C q a s means *closed quiet and steady*

This code contains several thousand characters or abbreviations, and to be able to use it to the best advantage, the press operator must memorize as much of it as possible. As so many abbreviations are used, it is impossible for the receiver to copy the matter in full as fast as it comes over the wire, and for this reason some sort of an ink register is necessary with which to receive the message. Several operators can be kept at work transcribing the despatches from the record on the paper ribbon as fast as it comes in, at the same time making, by some manifold process, a copy for each newspaper interested. A person desiring to engage in press work or who cares to study this subject, which is sometimes called *steno-telegraphy*, should obtain the complete Phillips code, which is published in book form.

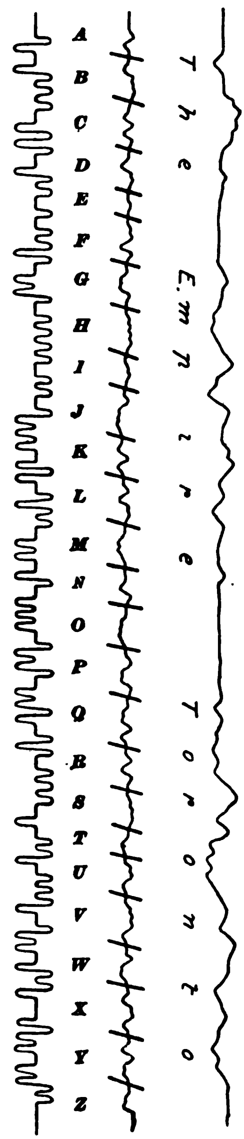
SENDING AND RECEIVING ON SUBMARINE CABLES

93. To become an operator for a submarine cable company the continental code must first be learned, then one must learn to read characters as they are reproduced by the receiving instrument, called the *recorder*, on the paper tape, a roll of which is termed the slip. It is then necessary to learn to send on the double key and to prepare sending tape with the perforator. Submarine-telegraph receiving and transmitting instruments will be explained in connection with submarine telegraphy. It might be stated here, however, that in submarine-cable systems, the double-current system is invariably used; that is, a current in one direction transmits a dot and a current in the opposite direction transmits a dash.

94. Alphabet as Received on Tape.—The letters of the alphabet, figures, and other characters are formed by prearranged combinations of positive and negative currents that cause corresponding right and left movements of the recording end of the receiving device, which is called the *siphon*. A small electric motor, known as the *mill*, causes the paper tape to be drawn along under the siphon which, when signals are being received, moves across this paper tape and leaves an ink record of its motion. The letter *a* consists of one positive and

one negative impulse, thus producing, to one facing the tape as it comes from under the siphon, one movement of the siphon to the left and one to the right; *b* consists of one negative and three positive impulses, producing one movement or kick of the siphon to the right and three movements or kicks to the left; and so on.

95. On the paper tape these signals appear as being above or below the zero line which the siphon, when at rest, traces along the center of the tape. There is necessarily no return of the siphon to its zero line every time between impulses. In the case of impulses of opposite polarity, the siphon will usually cross the zero position or line, but in the case of several impulses of the same polarity, the curve will merely fall back a little and move a little farther away each time from the zero line. If the continental code is deliberately sent over a very short cable, it will be traced by a siphon recorder about as shown in Fig. 11 (*a*). If the letters are sent continuously one after another, the actual record made by the siphon recorder connected to a long submarine cable is shown in Fig. 11 (*b*). The short slanting lines have been drawn to separate the letters. Fig. 11 (*c*), which is an accurate reproduction of a portion of a message actually transmitted over a transatlantic cable with the accompanying translation, will more clearly convey the character of the recorder signals. The message is



(*a*) (*b*) (*c*)

FIG. 11

translated and written down by the operator as the tape glides along in front of him.

96. Double Key.—Cablegrams are now transmitted both by hand and by automatic transmitters. The **hand,** or **double,** key is shown at K in Fig. 12. It consists of two long spring levers, or keys, a and b; one is operated by the first, or index, finger and the other by the second, or preferably by the third finger of the right hand. One lever a is known as the *dot key* and the other b as the *dash key*. To send the letter b, for instance, the dash key is pressed once and the dot key is pressed three times. One lever b is connected to the cable conductor or apparatus, and the other lever a is connected to the ground. The two levers normally press against the strip z which is connected to the zinc pole of the battery. The under strip c is connected to the copper terminal of the battery. When the lever b is pressed down, it leaves the strip z and touches the strip c. The circuit may then be traced from the ground to lever a–strip z–negative terminal of battery B–through the battery–strip c–lever b–to the cable conductor or apparatus. Thus the copper, or positive, terminal is connected toward the cable and the zinc or negative terminal to earth; hence the current flows toward the cable. When the other lever a is pressed down, the current will flow toward the ground. When both keys are pressing against the strip z, the line is connected directly to earth. This is a good feature, for it allows the cable to wholly or partially discharge whenever, in making a space between two succeeding signals, both keys touch the top strip at the same time. The rate of signaling is not over 20 to 30 words a minute where this key is used, because its manipulation is not so simple as that of the ordinary key used on land lines in the United States. Contacts on each key must be evenly and equally spaced and each letter must be equidistantly spaced. On some cables, the speed at which signals can be properly

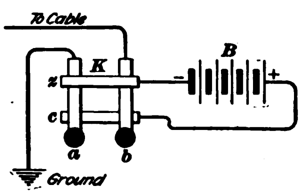


FIG. 12

transmitted and, therefore, the speed of sending depends on the condition of the cable.

Sending by means of the double key has been extensively used on submarine cables, but it is now being superseded by automatic transmitters. The accuracy and speed of the working is thus greatly improved, for by this mechanism is obtained the utmost uniformity of signal with a speed and tirelessness unattainable by hand.

97. Perforator.—The **perforator** is an instrument for perforating an oiled-paper tape with small circular holes. It has three keys. Depressing one key makes a dot and the unit space following it; depressing the second, or middle, key makes a space only; depressing the third key makes a dash and the unit space following it. The paper tape moves the required distance through the perforator automatically at each depression of a key. The keys are depressed with two small mallets, called *sticks*, which have rubber on one end. One stick is held in each hand. To learn to prepare tape on the perforator, first practice letters, then words, and finally complete sentences.

TYPEWRITING

98. The typewriter is extensively used for writing telegraph messages as the operator receives them from the sounder and also for transcribing messages from the receiving ribbon in certain automatic systems. An operator must be expert in the use of the typewriter in order to secure employment with the press associations. A good typewriter can write from 60 to 70 words a minute, but an expert telegraph operator cannot send steadily over 40 to 45 words a minute; consequently a receiver has plenty of time, in addition to writing the message, to insert the time received, the operator's private sign, etc., even when receiving at the fast rate mentioned. Every young operator should learn to operate the typewriter rapidly and accurately.

99. Typewriting Machines.—The typewriting machines of today are well-nigh perfect, and the telegraph operator

should not be careless, slovenly, or slow in his work with the typewriter any more than when manipulating the telegraph key. Typewriting machines are of two general kinds: **double-keyboard machines,** which have a key for each letter and character and **single-board machines,** called *shift-key machines,* on which each key has either two or three characters. When the keys have two characters, the machines have a shift key for moving the carriage from the position for lower-case letters to that for capital letters, one shift key being placed on each side of the keyboard for convenience in operation. When the keys have three characters, the machines have two shift keys, one of which is depressed for capital letters and the other for the third character on the key.

Figs. 13, 14, and 15 show three representative keyboards. The one shown in Fig. 13 is the double keyboard of the Smith Premier machine. The one shown in Fig. 14 is the single keyboard of the Victor typewriter, which is a single-shift-key machine, a shift key being placed on each side of the keyboard for convenience in shifting with the fingers of either the right or the left hand. The one shown in Fig. 15 is the single keyboard of the Oliver typewriter, which is a double-shift-key machine, one key being used to shift to the capital letters and the other to the figures and punctuation marks; both of these keys are placed on the left of the keyboard.

A keyboard on which the arrangement of letters is as shown in Figs. 13, 14, and 15 is known as a *universal keyboard,* which is the one now used almost exclusively. It will be noticed from a comparison of the keyboards that the arrangement of letters on the three keyboards is very nearly the same, and that the double keyboard is very nearly equivalent to two single keyboards. About the only difference in the arrangement on any universal keyboard is in the position of the keys for a few of the characters that are used the least.

100. In operating a typewriter, a person should sit directly in front of the machine, with both feet on the floor and the elbows on a level with the highest part of the keyboard. It is generally conceded that the **all-finger system of touch**

typewriting is the most practical and the only scientific one. By *all-finger* is meant using all the fingers instead of one or

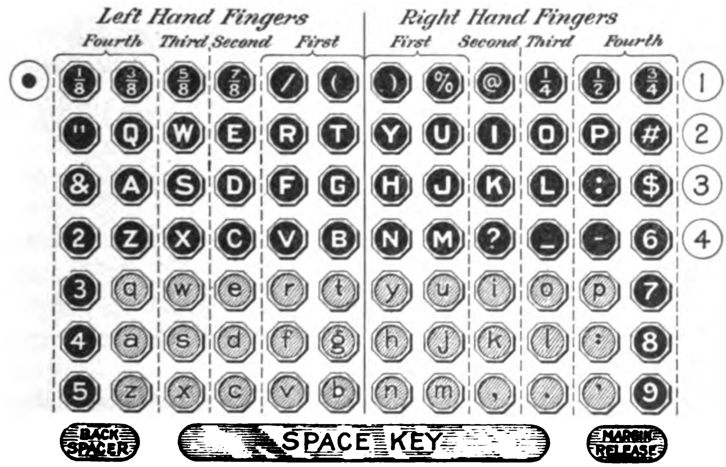


Fig. 13

two on each hand to operate the keys, and by *touch typewriting* is meant the placing of the fingers on the proper keys

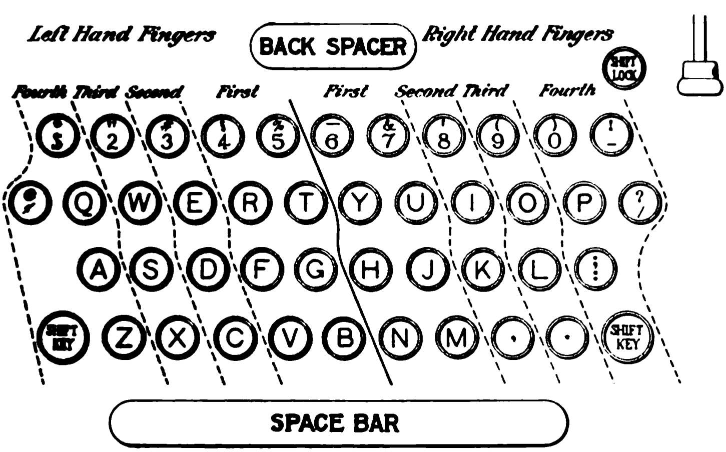


Fig. 14

without looking at them. It is the natural tendency for a beginner to keep his eyes on the keyboard all the time, but

diligent practice in the correct fingering of the keys will enable one to overcome this difficulty. The dotted lines between the rows of keys in Figs. 13, 14, and 15 indicate the rows that

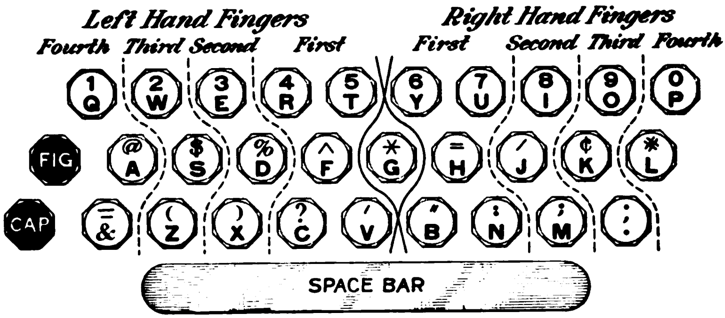


FIG. 15

should be operated by the different fingers, the space bar being operated by the thumb of either hand.

To acquire speed in typewriting, no better plan can be followed than that of writing words of frequent occurrence, phrases, parenthetical clauses, addresses, and short letters, over and over again, always being careful to use the correct fingering and never trying to write so fast that the work will not be done accurately. In both sending and typewriting, always work first for accuracy and then for speed. Each typewriter is accompanied with a book of directions for its operation and care; all directions issued by the manufacturers should be explicitly followed, especially those pertaining to the cleaning and oiling of the machines.

OBTAINING EMPLOYMENT

101. Applying for a Position.—Do not expect to get a position simply because you want it. If one is obtained, it will be because it is deserved. Therefore, a person should honestly feel that he can acceptably fill a certain position before applying for it. The candidate who, when calling for an interview, presents a neat, businesslike appearance, who introduces himself in a pleasant style of address, who can show that

he knows how to respect himself and at the same time be respectful to a possible employer, who is straightforward, frank, and unhesitating in answering all questions put to him, is sooner or later sure to obtain the position for which he is seeking.

102. Entering a Position.—Having secured a situation, do not consider the battle entirely won; it has just begun, and much hard work and study must yet be done. On taking up the duties of a new position, one must begin at once to adapt himself to the new surroundings and to fit himself to the place. One of the first considerations will be to find out those peculiarities of the business, either in technical language, figures, or routine, that are likely to prove troublesome in the work.

In a new position, one cannot be too careful, for his own sake, to start, and continue, on good terms with his fellow-workers. He should do nothing that will prejudice himself or his position in the estimation of his associates, for he will often be in need of some friendly assistance, which their experience will enable them to give him. Civility and cheerfulness cost nothing, and are very effective aids to one in any position of life—especially to one that is taking up new work. A pleasant manner and address, together with a good temper, help to smooth over the rough places and to ease the wear and tear of business life. Though cheerfulness and good temper are in a great measure governed by natural disposition, those that are not thus fortunately gifted may do much to neutralize the defects of an opposite character, and may, to a degree, cultivate the art of making friends. Care must be taken, however, that in the desire to be on good terms with all, the matter is not overdone. There is more in the quotation "Familiarity breeds contempt" than appears on the surface. While it is very natural for each to think his own method of doing a thing the best, it must also be borne in mind that it is not so much a person's duty to convert the company to his methods as to serve them by observing theirs.

ELEMENTARY TELEGRAPHY

(PART 1)

ELECTRIC TELEGRAPHY

HISTORY OF TELEGRAPHY

INTRODUCTION

1. **Electric telegraphy** is the art, science, or process of transmitting intelligible signals or signs between distant points by means of electric impulses moving between those points. Messages may be transmitted in this manner by visible or audible signals, both methods being largely used. The essential parts of the electric telegraph are the transmitting and receiving devices, and, also, except in wireless telegraphy, the line wire connecting the two distant points.

2. **Earliest Methods.**—Before the discovery and use of the voltaic pile, or battery, about 1800 A. D., several attempts were made to transmit signals to a distance by using electricity generated by friction. The first idea was to use a separate wire for each letter or character. In 1774, Le Sage, of Geneva, constructed an electric telegraph with twenty-four wires, one for each letter in the French alphabet, using frictional electricity as his agent of transmission. Lomond later simplified this method, using but one wire and a system of signals. Methods in which electric sparks and discharges from Leyden jars were used for signaling were devised about 1800, but nothing of practical importance resulted from these methods.

In 1809, Sömmering, of Munich, devised an electric telegraph based on the decomposition of acidulated water by an electric current and the giving off of bubbles of gas. He used a separate wire and key for each letter and a voltaic pile as his source of electricity. The ends of the wires projected in a row into the bottom of a long, narrow vessel under a series of inverted tubes, and, by closing keys at the sending station, bubbles of gas were produced and collected in the tubes at the ends of the corresponding wires at the receiving station. The letters of the alphabet could therefore be transmitted in any order desired. About the same time, Dr. J. R. Coxe, of Philadelphia, proposed, independently, a system very similar to that invented by Sömmering.

3. **Discovery of Electromagnet.**—After the important discovery of electromagnetism by Romagnési, of Trente, in 1805, and again, independently, by Oersted, of Copenhagen, in 1819, and the production of an electromagnet by Sturgeon, of England, in 1825, a fresh impetus was given to electric telegraphy. In 1828, Professor Henry, of Albany, New York, independently discovered that if he passed an electric current through an insulated wire that was coiled around a plain iron core, he could, at pleasure, magnetize and demagnetize the iron core. Thus, both Sturgeon and Henry produced the electromagnet, which is absolutely essential to nearly every method of electric telegraphy now in use.

GAUSS AND WEBER TELEGRAPH

4. The telegraphic apparatus invented by Gauss and Weber, of Göttingen, in 1833, was one of the earliest forms based on the discovery of Oersted. Fig. 1 shows the transmitter, and Fig. 2 the receiving instrument. The transmitter consisted of a standard *R*, in the center of which there were three large, straight, permanent magnets *b*, weighing 25 pounds each. The similar poles of these magnets were placed together and a coil *a* of insulated wire surrounded their upper ends. This coil contained 7,000 turns of insulated copper wire and was

wound on a wooden spool that had two handles *d* by which it could be moved up and down. The wires *l* and *l'* from this coil were connected at the receiving station, shown in Fig. 2, to the two wires *l* and *l'* of the flat rectangular coil *c*. To the ceiling was fastened the support *E*, from which was suspended, by a number of silk fibers, the mirror *n* and a flat permanent magnet *m*. This magnet was 18 inches long, and was free to vibrate inside of the coil *c*. At a distance of about 12 feet was placed the telescope *T* and the scale *S*, by which means a very small deflection of the magnet *m*, to which the mirror *n* was rigidly fixed, could be observed.

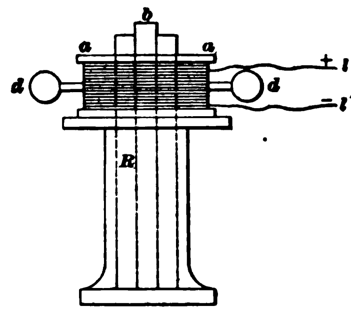


FIG. 1

5. By raising the spool of wire *a* at the transmitting, or sending, office, an electromotive force was induced in the coil *a*, and a current of electricity would flow through the circuit in one direction. This current, passing through the coil *c*, caused the magnet *m* to rotate and thus produce a deflection of the mirror in a direction that could be

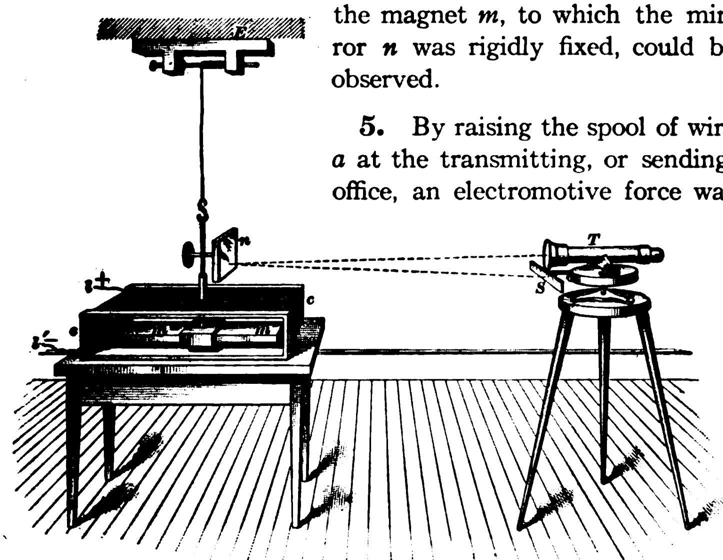


FIG. 2

observed by looking through the telescope. By lowering the coil, the induced current flowed through the circuit in the opposite direction and produced a deflection of the mirror in the opposite direction. By the combinations of right and left deflections, an alphabet was arranged.

6. Professor Steinheil, of Munich, developed this invention of Gauss and Weber, finally producing a transmitter and an ink-recording receiver capable of transmitting and receiving messages at the rate of 6 words per minute. He was anticipated, however, in the idea and construction of a self-recording receiver by Morse. But Steinheil's apparatus was too complicated to compete with the newer and simpler devices that were brought forwards. Professor Steinheil was the first to discover that the earth could be used as one conductor, and that but one line wire was necessary, the earth being used as the return circuit. He made this discovery in 1837, while attempting to use the rails of a railway as telegraphic conductors.

MORSE TELEGRAPH

7. The possibility of utilizing Professor Henry's electromagnet for an electric telegraph system was conceived by an American portrait painter, Samuel F. B. Morse, in 1832. He worked diligently on his system, but was unable, for the lack of money, to apply for a patent until 1837. Morse's first ideas on telegraphy included the following apparatus and method: A voltaic cell as a source of electricity; outgoing- and return-wire conductors; a system of signals consisting of dots and spaces to represent numbers; a method of sending electric impulses representing these dots, and the use of an electromagnet at the receiving end that caused a pencil to draw, nearly at right angles across a moving paper, one V-shaped mark for each electric impulse. By counting the number of marks across the paper between two spaces, the spaces being indicated by long, straight lines lengthwise of the paper, and by looking up the number in a telegraphic dictionary, the corresponding word could be found.

8. Morse's First Apparatus.—The first model constructed by Morse, in 1835, is shown in Fig. 3, where *T* is the transmitting, and *R* the receiving apparatus, *B* is the voltaic cell, and *l* and *l'* are the two line wires. It was not then known that the earth could be used as a return circuit, so two wires were employed. The transmitter consisted of a stout piece of wood on which were fixed two rollers *b* over which ran an endless belt. To this was

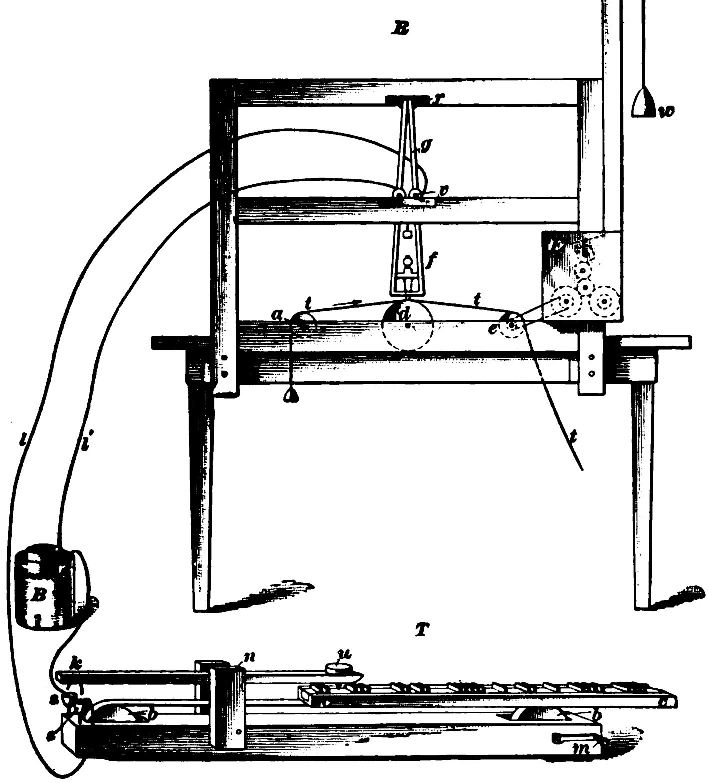


FIG. 3

attached the composing stick *c*. On this composing stick the symbols, or types, shown in Fig. 4, could be arranged in any

order desirable. At *n*, Fig. 3, was pivoted a lever, on the front end of which was a weight *u* to keep that end depressed. By turning the handle *m*, the composing stick with its type was moved along, and every time one of the projecting pegs of the type came against the wedge under *u*, that end of the lever was lifted up, causing the two ends of a bent piece of wire *k* to dip into two mercury cups *s* and close the circuit of the battery *B*. Thus, every time a peg passed under the weight *u*, an electric impulse was sent over the line to the receiving apparatus *R*.

9. The important part of the receiving apparatus was an electromagnet *v* secured to an artist's wooden stretching frame, the iron armature of the magnet being fastened opposite to

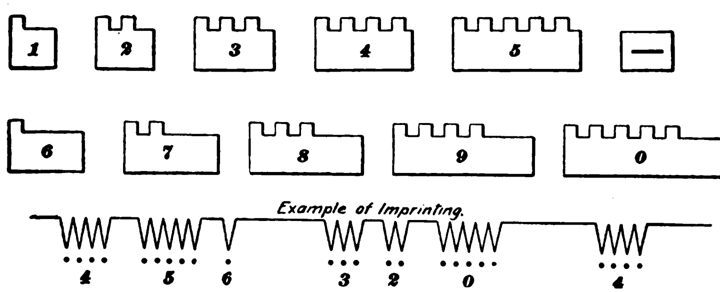


FIG. 4

it on a sort of pendulum *g* hanging from an axis *r*. At the bottom of the pendulum was a tube to hold a lead pencil on which rested a weight to press the pencil against a ribbon of paper *t*. This paper was kept moving steadily over the drums *a*, *d*, *e* by means of the clockwork *E* and the weight *w*. The pendulum *g* in its normal, or at rest, position, where a weight and, later, a spring tended to keep it, caused the pencil to make a straight line in the direction of the motion of the paper.

Whenever a current was sent over the line and through the electromagnet *v*, by closing the circuit between the mercury cups *s*, the armature was attracted, pulling the pendulum with it and causing the pencil to draw two lines nearly at right angles to the direction of the motion of the paper,

one line as the pendulum moved toward the magnet, due to the attraction, and another as it returned to its original position after the current had ceased to flow. The **V** thus made would represent a single impulse.

10. The type used in the transmitting apparatus at one end of the line and the record made by the receiver at the other end are shown in Fig. 4. Both the sending and the receiving apparatus were automatic in action after the type characters were set. The meaning of one type character depended not only on the number of pegs projecting upwards, but also on the length of the space following the last peg on the type.

11. Morse exhibited his apparatus at various times before the faculty of New York University, the Franklin Institute

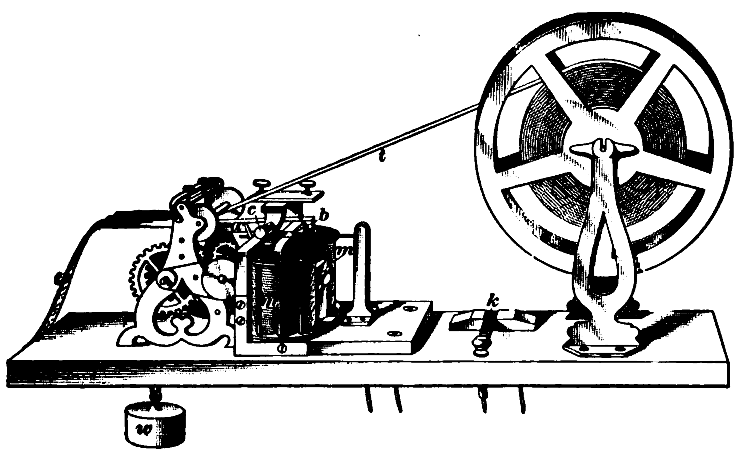


FIG. 5

at Philadelphia, and, finally, before President Van Buren. In 1843, a bill was finally passed through Congress appropriating $30,000 for the purpose of erecting an experimental line between Washington and Baltimore. Morse kept improving his system so that, by 1844, the apparatus consisted of an electromagnetic circuit-closing device called a *relay*, an embossing register, and a simple circuit-closing key at each end of the line. About this time was developed the Morse telegraph

code consisting of a different combination of dots, dashes, and spaces for each letter, numeral, and punctuation mark.

12. Morse Embossing Register.—In Fig. 5 is shown the Morse recording apparatus or embossing register, as it is called, and a key mounted on the same baseboard. To one end of the lever *a*, which is pivoted at *c*, is fastened the armature *b*, and to the other end are secured three steel points, which indented or embossed the paper ribbon as it was drawn along by the clockwork and weight *w*. There seems to be no good reason for using three steel points, for one record has since proved to be sufficient. When the armature was attracted by the electromagnet *m* the steel points pressed the paper upwards into three corresponding grooves in a roller, against which the paper *t* was pressed as it was drawn along. A depression, or indentation, in the paper stood for a dot or a dash, depending on its length. Thus, indentations representing dots and dashes, and separated by intervening unindented portions representing spaces, formed permanently embossed characters on the paper. The key *k* mounted on the same base was a very simple affair. When not in actual use by the operator, a metallic plug was placed between the contact points, to keep the circuit closed.

13. First Use of Relay.—On the Baltimore-Washington line, Morse used an electromagnetic relay, connecting the coils of his embossing register in a separate circuit, the opening and closing of which was controlled by the armature of the relay, as shown in Fig. 6. In this complete diagram of the connections at both ends, R and R' represent the relays; S and S', the coils of the embossing registers; K and K', the keys; B, the battery; and G and G', the connections with the ground. The relays R and R' are connected in series with the line, the battery B, and the two keys K and K'. The relays control the opening and closing of the local circuits of the two registers S and S'. When both keys K and K' are closed, the electric current flowing in the relay coils magnetizes the iron cores of the relays, causing the armatures of the two relays to be attracted, thereby closing the two local circuits, one at each end of the

line, in which are connected the registers S and S' and so-called local batteries. If either key K or K' is opened, both local circuits will be opened. When the local circuits are closed, the styles of the registers make indented marks on the paper corresponding to dots and dashes, and when the local circuits are open, the styles are withdrawn from the paper and no indentations are made, thus separating the dots and dashes by spaces.

14. The telegraphic alphabet, called the **Morse alphabet,** as arranged and used for telegraphing between Baltimore and Washington, is still employed all over the United States

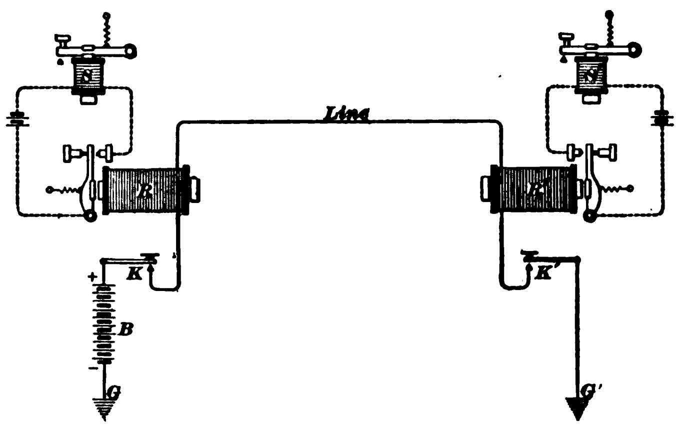


FIG. 6

and Canada, except for submarine-cable work. About the first public news to be sent over the Baltimore-Washington line was the report of a national political convention in session at Baltimore in 1844. The relay used by Morse over this line was an exceedingly large and clumsy affair, weighing 150 pounds; the relay of today weighs only 3½ pounds.

15. Ground Returns.—By an accident to the insulation of the line circuit, it was discovered that only one wire was necessary and that the earth could be used as one path for the current. This was also discovered independently, by Professor Steinheil in 1837. The insulation between the two line conductors that Morse at first used becoming defective, the

system of connections shown in Fig. 6 was tried; that is, instead of employing a second wire as a return path, the circuit was connected to the ground G and G' at each end and the earth used as a return path. This system of connections is used today all over the United States, Canada, and Mexico where relays and registers, or sounders, are employed.

16. Work of Alfred Vail.—Alfred Vail is usually given the credit for the discovery of the fact that the characters could be read by the sound made by the recording lever, as well as by the marks made on the paper. This led to the use of a sounder, on account of its simplicity, and the recording apparatus was dispensed with. The method of communication originated by Morse and developed by Morse and Vail, including both the alphabet and the arrangements of the line and local circuits and apparatus, has been continued in general use ever since, with the addition of such practical improvements as experience has from time to time suggested.

To Alfred Vail, a skilful mechanic and inventor, who became a partner of Morse in 1837, considerable credit is due for the success of Morse's system. He entirely reconstructed the apparatus and embodied in it many practical features, and prevailed upon his father, Stephen Vail, to supply the money whereby the development and introduction of the electric telegraph became possible. His efforts in overcoming many of the practical difficulties that arose in connection with the first telegraph line between Baltimore and Washington, in 1844, and his genius and untiring diligence during the development of the telegraph deserve a great deal of praise. It is claimed that he put the Morse telegraph code into its present practical and satisfactory form, and the register that he made in 1844 has been improved but little since that time.

COOK AND WHEATSTONE TELEGRAPH

17. Cook and Wheatstone took out their first joint patent in England in 1837, and their first actual working telegraph circuit was erected in 1838. For this system, six wires and five magnetized needles, enclosed in wire coils, were used,

combinations of deflections of the needles forming a system of signals. The modern single-needle apparatus, of which there were over three thousand in use in Great Britain, was first employed on a public line running out of London in 1845. This apparatus was a combination of the ideas of both Cook and Wheatstone. The combination of right and left deflections of a single vertical pointer in front of a dial furnished a system of signals representing the letters of the alphabet. The pointer was attached to the axis of a vertical, thin iron bar permanently magnetized, and it was deflected to the right or left, depending on the direction of the electric current that was sent through the coil of wire surrounding the thin iron bar.

AUTOMATIC AND CHEMICAL RECORDING SYSTEMS

18. About 1854, two competing systems of telegraphy were introduced in this country. One was the House printing telegraphy, by which the message was delivered on a ribbon of paper, plainly printed in Roman letters. The other was a system devised by Prof. Alexander Bain. It recorded dots and dashes by the chemical discoloration of the recording paper. Both were operated with reasonable success, but neither seemed able to compete with the relay and sounder, probably on account of the simplicity and efficiency of the latter.

19. Chemical Recorder.—The extreme sensitiveness of the Bain recorder to feeble currents warrants a brief description of it here, but the description of printing and chemical telegraphy systems is given more fully later. In Fig. 7 is shown Bain's chemical telegraph, or **electromotograph,** as it is called. The lever l is pivoted on a universal joint at H. The spring t pulls the lever l to the left, and the spring s causes the platinum-tipped screw c to be pressed against the paper p. The metal drum g is revolved continuously by clockwork in the direction shown by the arrow. If this is to be used as a relay to control the opening and closing of a local circuit, the zinc pole of the battery B, for the reason that will be presently given, must be connected to the screw c, and the copper

pole through the key *k* to the shaft of the drum *g*, although the reverse is shown. A local circuit containing an electromagnet *S* and a local battery *L B* may be connected, as shown, to the lever *l* and the stop *d*.

20. When the key is closed, a current flows from the battery *B* through the key *k*, the metal drum *g*, and the moistened paper *p* to the platinum-tipped screw *c*, and back to the battery *B*. The paper is moistened with a solution of common salt and pyrogallic acid. When no current is passing

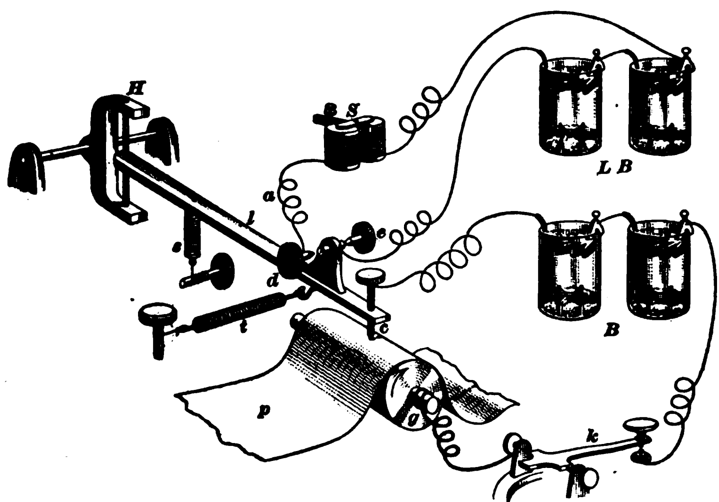


FIG. 7

through the paper, on account of the key *k* being open, the friction between the paper and the platinum-tipped screw *c* is sufficient, with the springs *t* and *s* properly adjusted, to keep the lever *l* pressing against the stop *e*. But when the key is closed, the current flowing from the roller *g* through the paper to the screw *c* decomposes the chemicals, rendering the paper so slippery to the platinum tip *c* that the spring *t* easily pulls the lever against the stop *d*, thus closing the circuit containing the electromagnet *S* and the local battery *L B*.

If the paper is moistened with a solution of iodide of potassium and starch in water, and the positive, or copper, pole

of B connected to c, as is here shown, a permanent blue line will be made on the paper whenever the current is flowing, thus giving a permanent record of the message, and no sounder would be necessary. By its use, messages may be transmitted and received by currents so weak that the ordinary electromagnetic relay would fail to operate or even give an indication of the passage of the current. Two cells, it is said, will operate it over a line 200 miles in length.

TELEGRAPH CIRCUITS

INSTRUMENTS USED

21. **Telegraph Key.**—The only instruments really necessary at each station on the simplest form of the Morse telegraph circuit, when the line does not exceed 20 or 30 miles in length, are a *telegraph key* and a *telegraph register*, or *sounder*. The telegraph key is an instrument for opening and closing the circuit. By this operation, various combinations of long and short current impulses are sent over the circuit.

22. **Telegraph Sounder.**—A telegraph sounder consists of an electromagnet and a pivoted armature, adapted to give forth a sound whenever an electric current starts or stops flowing through the coils on the instrument. When the current starts to flow through the coils on the sounder, the iron armature is attracted and a lever, to which the armature is fastened, strikes a stop and produces a loud click. When the current stops flowing through the coils, the armature is no longer attracted, and a spring quickly pulls it back to its first position, causing the lever to strike another stop and so produce another loud click. The interval of time that elapses between two such clicks determines whether the signal is a dot or a dash.

MORSE CLOSED-CIRCUIT SYSTEM

23. The simplest form of a telegraph circuit is shown in Fig. 8, where L represents the line wire connecting the two stations W and E, K and K' are keys, B represents a battery,

S and S' are sounders for receiving messages, G and G' are metallic plates by means of which the wires are connected with the earth, or *grounded*, as it is usually termed. The circuit is traced as follows: When both keys K and K' are closed, the current starts from the positive, or plus, pole of the battery B and passes through the key K–sounder S–the line L–the sounder S'–key K'–plate G' at station E–back through the earth to G and the negative, or minus, pole of battery B. The earth is generally used instead of a return wire, and may, for all practical purposes, be considered as a conductor of very small resistance, for, although it is comparatively a poor con-

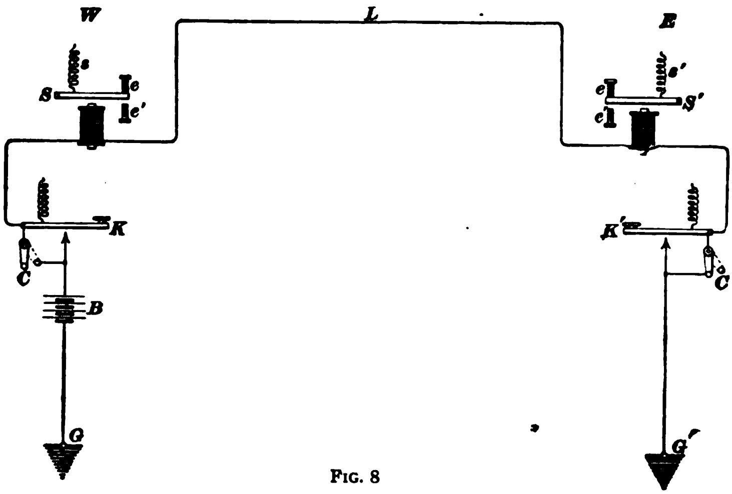


FIG. 8

ductor, its practically unlimited area renders its resistance negligible in comparison with that of a long line wire.

When both keys are closed, electricity will flow around the circuit, so that the electromagnets of the sounders will attract their armatures. If, now, one key is opened, the current will be interrupted, and both electromagnets will release their armatures and allow them to be drawn upwards by the springs s and s'. If the key is closed again, both armatures will be drawn down as before. The motion of the armature is limited by the stops e and e'. The downward movement of the armature causes a sound distinguishable from that made by the

upward movement, and these movements are called the *down* and *up strokes*. Messages are read from the sounds and the intervals between them.

24. Each key is provided with a small switch C and C' for closing the line when it is not in use. Closing one of these switches accomplishes exactly the same result as depressing the key. It saves the operator the inconvenience of having to hold down his key when he wishes to leave the circuit at his station closed for some time. In Fig. 8, the switches C and C' are in the proper positions to enable the operator at station W to send to station E. The position of the switches indicated by the dotted lines is that required for sending from station E to station W. When telegraphing, the switch at the receiving station must be closed, and that at the sending station open. When the line is idle, both switches must be closed. The necessity for these rules concerning the use of the switches will be appreciated by supposing that the operator at E has left his switch open. It will then be impossible for the operator at W to control the sounder at E, for, no matter whether the circuit is open or closed at W, it is open at E, and therefore no current can pass over the line.

This arrangement is known as the **Morse closed-circuit system,** because, in the normal condition, that is, when no messages are being sent, all the keys are closed and the battery is connected to the line, causing electricity to be normally flowing through the whole circuit. This system is used all over the United States, Mexico, and Canada, except for submarine-cable telegraphy.

25. Relay Circuit.—When a telegraph line is more than about 30 miles in length, it becomes difficult and impracticable to render the current in the line circuit strong enough to operate the somewhat heavy armature of a sounder with sufficient vigor to produce a loud enough sound. The sounder is then replaced by an electromagnetic device called a *relay*. A **relay** is a telegraphic receiving instrument having an armature that moves in accordance with impulses of currents that pass through the coils on the magnet cores of the instrument,

and, in so moving, opens and closes a second circuit, called a *local circuit*, in which may be included a sounder and as powerful a battery as desirable; the relay, on the other hand, may be so delicate as to work with a very weak current. A typical relay includes an electromagnet, the two coils of which are generally wound with many turns of fine wire, and a small, light armature. When a current passes through the coils of the relay, the armature is attracted toward the magnet until its upper end touches a contact screw and so closes the local circuit. When the current ceases to flow through the coils of the relay, the armature is no longer attracted, and

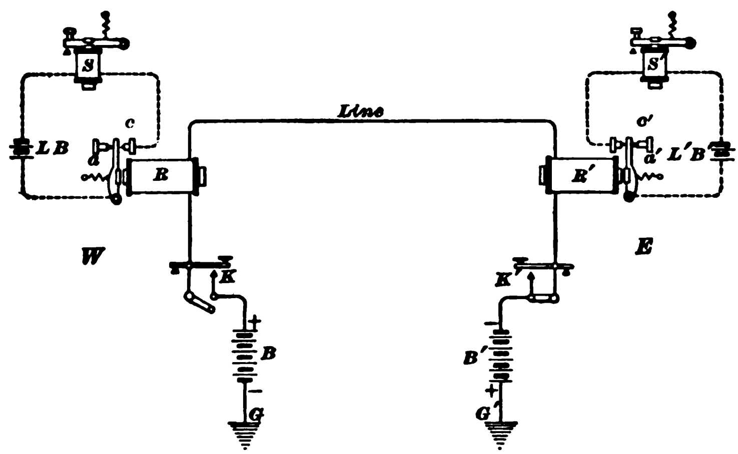


FIG. 9

a spring promptly pulls it away from the magnet and the contact screw and causes it to rest against a second screw with an insulated point. Thus the local circuit is opened as the armature leaves the first-named screw.

26. The arrangement in which relays are used at two telegraph offices *W* and *E* is shown in Fig. 9, where *R* and *R'* are the relays; *K* and *K'*, the keys; *B* and *B'*, the main-line batteries; *L B* and *L' B'*, the local batteries; *S* and *S'*, the sounders; and *G* and *G'*, the ground connecting plates. Batteries *B* and *B'* are called the ***main-line batteries*** because they are connected directly in the main or line circuit; *L B* and *L' B'*

are connected with the sounders in circuits that do not go outside of the office and, hence, are called *local batteries;* and the circuits containing them are called local circuits. A current starting from the battery B passes through the key K–relay R–line-relay R'–key K'–battery B'–ground plate G', and returns through the earth and the ground plate G to the battery B. The batteries B and B' are in series with each other, one battery B having its negative pole to earth and positive pole to the line, while the other B' has its positive pole to earth and its negative pole to the line. When the circuit is closed, both relays are energized and attract their armatures a and a'; and when the circuit is opened, both relays lose their magnetism and release their armatures. The armatures a and a', therefore, make and break the two local circuits at contacts c and c', and thus act as keys in the local circuits, each of which contains a register, or sounder, and a battery.

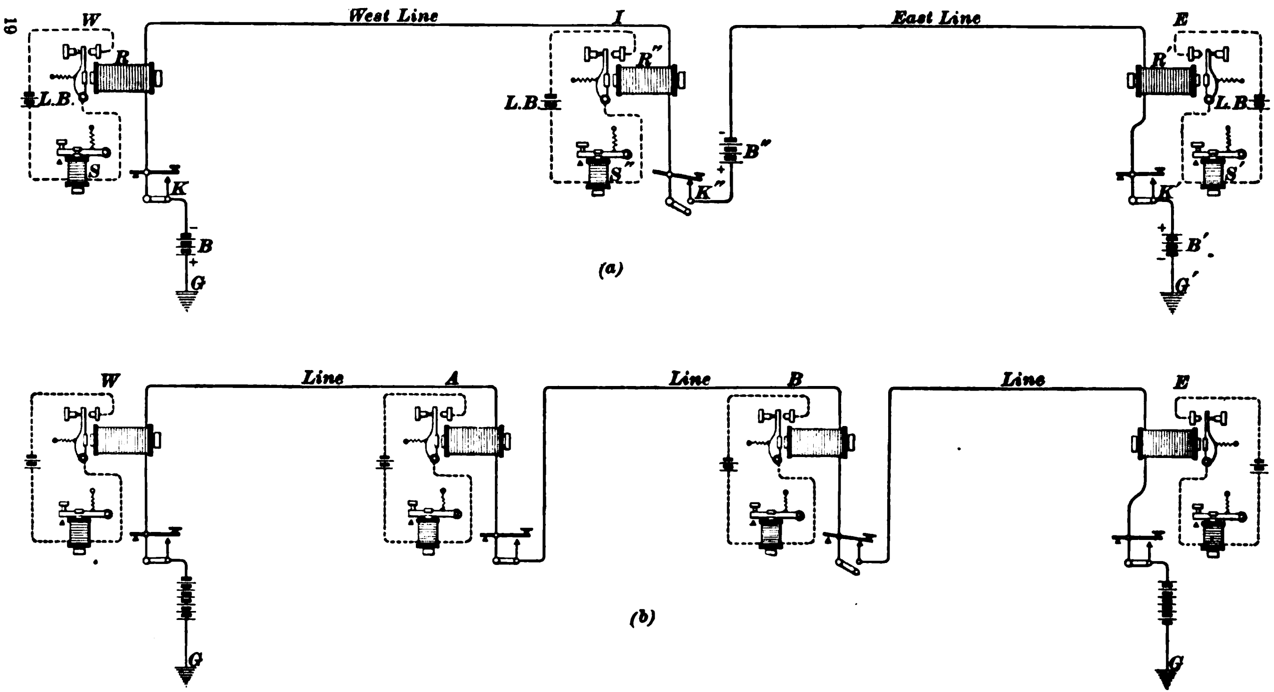
27. Action of Relay Circuits.—When the telegraph operator at one office desires to send a message to the other, he interrupts the flow of the current by opening the switch of his key. This causes the relays to lose their magnetism, release their armatures, and open both the local-sounder circuits, thus causing the sounders to click. If he operates his key by closing and opening the circuit so as to form the characters representing the letters of the alphabet in the order in which they occur in a message, the armatures of his own and the distant relays, as well as those of the sounders controlled by them, will respond to every make and break in the circuit caused by operating the key, and the message may be read by ear from the clicks made by the sounders. As the sending operator's sounder also responds and gives out the message, the receiving operator can interrupt him at any time by opening the line circuit at his key and thus stopping the current through the relays. The sending operator thereby realizes that the circuit has been broken, because his own sounder no longer responds to the movements of his own key. He then closes his switch to give the receiving operator an opportunity to communicate with him.

28. Local Batteries.—As many cells of battery as are necessary may be used in the local circuit at *L B*, Fig. 9, and thus the sounder may be made to produce a loud sound even if the current in the line wire is exceedingly feeble. One cell is often sufficient, but it is customary to use two cells in the local-sounder circuit. Except in large offices, where dynamos or storage batteries are used, all current for both main-line and local circuits is usually obtained from gravity or crow-foot cells.

29. Intermediate Offices.—Sometimes as many as fifty intermediate offices are connected in the same circuit with the two terminal offices, but twenty are probably as many as can be worked to advantage. Only one operator can be sending at one time, but all the others may receive the message, which may be of interest to only one or two offices on the line, but all the other offices have to remain idle until the one sending is through, or else interrupt him if the other business is so much more important that it is allowable to do so. Where bulletins or circular messages are sent daily by one office to all stations, it is advantageous to have as many offices as practicable on one line.

30. Arrangement of Intermediate Offices.—In Fig. 10, (*a*) shows one intermediate office *I* connected in the line between the two terminal offices *W* and *E*, with one-third of the whole number of main-line cells at each office. View (*b*) shows two intermediate offices *A* and *B* and two terminal offices *W* and *E* on the same circuit with one-half the whole number of main-line cells at each terminal office and none at the intermediate offices. All keys, relays, terminal and intermediate main-line batteries are connected in series in the same line circuit.

All the cells for supplying current in the main-line circuit may be located at one terminal or end station, as in Fig. 6, or one-half the number may be at each end station, as in Fig. 10 (*b*), or the cells may be distributed, some being placed at each station, as shown in Fig. 10 (*a*). Where several sets of cells are used, the cells in each set must not only be connected in series



W
R
L.B.
S
K
B
G
West Line
I
R″
L.B.
S″
K″
B″
(a)
East Line
E
R′
L.B.
S′
K′
B′
G′
W
Line
A
Line
B
Line
E
G
(b)
G

FIG. 10

with one another, but the various sets must be connected in series in the circuit and not opposing one another.

To connect the line batteries properly, when there is a battery at each office, as shown in Fig. 10 (*a*), start at station *E*, for instance, and there connect the zinc, or negative, pole of the battery B' to the ground plate G', and the copper, or positive, pole through the key K' and relay R' to the line; at the intermediate station, connect the east line to the negative pole of the battery B'', the positive pole through the key K'' and relay R'' to the west line, and at the west station connect the line through the relay *R* and key *K* to the negative pole of the battery *B*, the positive pole being connected to the ground plate *G*.

31. Intermediate Batteries.—It is not very often necessary to connect batteries in the line at small intermediate stations. The best arrangement is to have an equal number of cells at each terminal station. When one terminal station is large and well equipped with dynamos, which are now extensively used for supplying the current for telegraph lines, and the other station is not so well equipped, it may be advantageous to let the former station supply all the current. Furthermore, where the intermediate office is a large one, well equipped with dynamos for use as intermediate batteries, and the terminal offices are small the whole current may be advantageously supplied from the intermediate-office dynamo, and no batteries need be used on such a line at the terminal offices.

MORSE OPEN-CIRCUIT SYSTEM

32. In Europe, what is known as the **Morse open-circuit system** is used. This system, with two terminal offices and one intermediate office on one line, is shown in Fig. 11. When all the keys are at rest in their normal position, that is, when no message is being sent, all the keys and batteries are so arranged that all batteries are on open circuit, although all the relays are connected in series in the circuit. Thus, normally, no current flows through the line or through the local-sounder

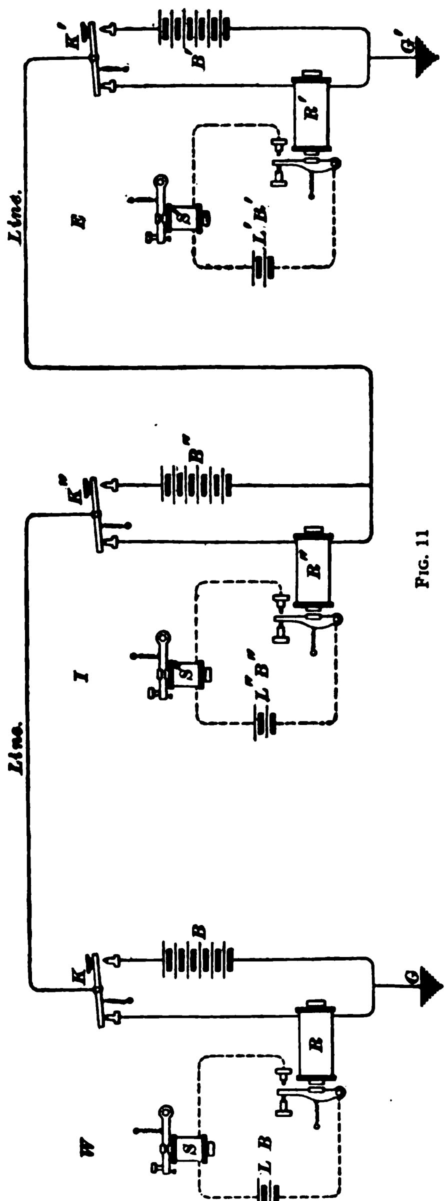


Fig. 11

circuits, and the batteries are all on open circuit, from which fact it derives its name. When a message is to be sent, the sending operator closes his key, the battery at his station is introduced into the line circuit, and his relay is cut out. Thus, current is sent over the line operating all but the home, or sender's relay. It is a simple matter, however, to so connect the relays that the home relay will be operated by the home key.

In Fig. 11, R, R', and R'' are the relays; S, S', and S'', the sounders; B, B', and B'', the main-line batteries; K, K', and K'', the keys; and $L\ B$, $L'\ B'$, and $L''\ B''$, the local batteries for operating the local sounders at the W, E, and I offices, respectively. Although the like poles of all the batteries B, B', and B'' are connected to the front contacts of the keys, for the sake of uniformity, this is not at all necessary, however.

COMPARISON OF OPEN- AND CLOSED-CIRCUIT SYSTEMS

33. Advantages and Disadvantages of Closed-Circuit System.—In the closed-circuit system, the whole battery may be located at any one station or divided up among any number of stations; this gives the closed-circuit system a decided advantage over the open-circuit system where there are a large number of offices on one line. As the current is flowing even when not sending, the system may be easily kept in adjustment, ready for sending and receiving messages at short notice. The cells, being normally on closed circuit, maintain a more constant electromotive force and do not run down when the line is being used, and, as a result, the current is apt to be more even and steady than on the open-circuit system.

But, as the current is flowing constantly, the battery material is being steadily consumed whether the line is in use or not. A continuous current seems to increase flaws in cables, for which reason the closed-circuit system is not used for submarine telegraphy. If all the cells are at one end, the current due to leakage between the line and the ground will be strongest at the office nearest to, and weakest at the office farthest from, the battery. If serious enough, this can sometimes be partly reduced by distributing the cells among the various offices.

34. Advantages and Disadvantages of Open-Circuit System.—In the open-circuit system, consumption of battery materials takes place only when the line is being used. It is suitable for submarine-cable work. The resistance of one relay is cut out of the circuit when a key is closed. But with this system, it is necessary to have the same number of cells at each office and a sufficient number to operate the whole system; and as it is not likely that the batteries at all stations will be in the same condition, all the relays may need readjusting whenever a different office starts to send. The current is not apt to be as steady as in the closed-circuit system. If there is leakage on the line, causing the current to be stronger at the sending office, there is no means to avoid it except by improving the insulation of the whole line.

SPEED OF TELEGRAPHING

35. In a telegraph tournament held in New York in May, 1898, the winner in the championship 5-minute sending contest sent 254 words with only one error, and his Morse was said by the judges to be perfect. The highest recorded speed of legible telegraphy, in which the Morse code was used, was made in a previous contest in which 265 words were sent in 5 minutes. An expert operator can send from 35 to 40 words per minute, but a steady working rate of 25 to 30 words per minute is regarded as good.

TELEGRAPH CODES

36. Telegraph codes consist of combinations of dots, dashes, and spaces, which represent letters, numerals, and punctuation marks. Although several codes are in use, the dot is taken as the unit by which the lengths of the dashes and spaces are measured. The generally accepted relative lengths of the different dashes and spaces are as follows:

Signal		Duration of Signal
Dot	1	1 unit
Dash	3	3 units
Long dash (*l*)	5	5 units
Extra-long dash (cipher)	7	7 units
Space between parts of a letter	1	1 unit
Space in spaced letters	2	2 units
Space between letters	3	3 units
Space between words	6	6 units

There are four lengths of spaces and three of dashes, or four including the dot. Theoretically, the long dash (*l*) should be twice as long as the dash, and the extra-long dash (*0*, cipher) should be one-half longer than the long dash (*l*); that is, it should be 9 units in length when *l* is made 6 units. However, the long dash (*l*) is seldom made longer than 5 units and the

cipher seldom longer than 7 units. Furthermore, in practice, the *l* and *0* (cipher) are frequently made the same. In that case, when they occur alone or in words, the long dash would be read as *l*, but when found among figures it would be translated as *0* (cipher).

A material gain in the rapidity of transmission may be effected, and without any great disadvantage, by shortening the dash to 2 units, the long dash to 4 units, and the extra-long dash to 5 units and making the spaces, also, proportionately shorter. When recording instruments are used, this shortening of the dash is not so advisable, for it is then very easy to mistake a dash for a dot.

37. Morse Code.—The different telegraph codes are the *Morse*, the *Continental*, the *Bain*, and the *Phillips punctuation;* the Bain code, though, is seldom if ever used. The system of combining dots, dashes, and spaces to represent the letters, numerals, and punctuation marks, as arranged by Vail or Morse, or both, is known as the *American Morse*, or more often, simply as the *Morse code*. On circuits equipped with Wheatstone apparatus two dots and two dashes (figure 7 reversed) is used for the letter *l*. Except for submarine telegraphy and at most wireless telegraph stations, the Morse code for letters and numerals and the Phillips code for punctuations are used throughout the United States and Canada.

The Australian colonies (except West Australia and New Zealand, where the Continental code is used) employ a modification of the Morse code. The characters that differ from the Morse are the following: *C* -——-- for -- -; *O* -——— for - -; *R* --——-— for - --; and *Z* ————— for --- -; *underline*, or *italics*, —----— —----—; *bracket*, or *parenthesis*, -—--- -—----; *quotation*, -—-—— -—-—— -—-—— -—-——, altered generally to -- -- -- --; quotation within a quotation, "' '", -- --. The period, interrogation, and exclamation marks, which are the only other punctuation marks in general use in those colonies, are exactly the same as the Morse. With them, the exclamation mark is generally used to express mirth or laughter.

ALPHABETS

Letters	Morse	Continental	Bain
A	·—	·—	·—
B	—···	—···	·—·
C	·· ·	—·—·	···
D	—··	—··	··—
E	·	·	·
F	·—·	··—·	·———
G	——·	——·	·—··
H	····	····	·——
I	··	··	··
J	—·—·	·———	···—
K	—·—	—·—	·——·
L	⸺	·—··	····
M	——	——	·—·—
N	—·	—·	··——
O	· ·	———	⸺
P	·····	·——·	—·—
Q	··—·	——·—	—·—·
R	· ··	·—·	——·
S	···	···	—··
T	—	—	—···
U	··—	··—	—·
V	···—	···—	———·
W	·——	·——	——··
X	·—··	—··—	—··—
Y	·· ··	—·——	——
Z	··· ·	——··	———
&	· ···		————

NUMERALS

Figures	Morse	Continental	Short Continental
1	·——·	·————	·—
2	··—··	··———	··—
3	···—·	···——	···—
4	····—	····—	····—
5	———	·····	·
6	······	—····	—····
7	——··	——···	——···
8	—····	———··	—··
9	—··—	————·	—·
0	⸺	————— or —·	—

PUNCTUATIONS, ETC.

		Morse	Continental		Phillips
.	Period	..--..	.. .. ..		..--..
:	Colon	-.- ..	---...	*KO*	-.- ..
:—	Colon dash			*KX*	-.- .-..
;	Semicolon	.-.-.	-.-.-.	*SI*	... ..
,	Comma	.-.-	.-.-.-		.-.-
?	Interrogation	-..-.	..--..		-..-.
!	Exclamation	---.	--..--		---.
–	Fraction line	.	--		.
—	Dash			*DX*	-.. .-..
-	Hyphen		-....-	*HX*	.... .-..
’	Apostrophe		.----.	*QX*	..-. .-..
$	Dollars			*SX*	... .-..
c	Cents			*C*	.. .
£	Pound sterling			*PX*	..... .-..
/	Shilling mark		...		..- -
d	Pence			*D*	-..
	Capitalized letter			*CX*	.. . .-..
:“	Colon followed by quotation			*KQ*	-.- ..-.
.	Decimal point		.--.	*DOT*	-.. . . -
¶	Paragraph	----	--. --.-		----
	Italics or underline	-...-.	.-.. .-..	*UX*	..- .-..
( )	Parenthesis	.-..-	-.- -.-	*PN*	..... -. ..... -.
[ ]	Brackets			*BX*	-... .-.. -... .-..
“ ”	Quotation marks	.-.---.-	.-. .-.	*QN*	..-. -. ..-. -.
”	End of quotation		.-. .-.	*QJ*	..-. -.-.
“‘ ’”	Quotation within a quotation			*QX*	..-. .-.. ..-. .-..
’	End of quotation within quotation			*QY*	..-. .. ..

38. Phillips Punctuation Code.—The Phillips punctuation code has superseded the Morse for punctuations, and is much more complete and systematic. In such characters as parenthesis ( ), brackets [ ], quotation marks " ", *italics*, etc., which are composed of two parts separated by one or more words, the characters representing them must be sent before and after the intervening word or words. The following modifications are included in the Phillips code:

----- -- -- *PY* for the second parenthesis mark in place of *PN*, which stands for the first parenthesis mark as formerly.

--—- —-—- *QJ* for the second quotation mark in place of *QN*, which still stands for the first mark, as formerly.

--— —-—- *UJ* for the second underline signal in place of *UX*, which stands for the first underline signal, as formerly. The paragraph means that the receiving operator should commence a new line. : " (colon followed by quotation) is —-— --—-.

39. Continental Code.—A modification of the Morse code, called the Continental, is used all over the world for submarine telegraphy, and for land telegraphy in almost every country except the United States, Canada, and parts of Australia and for wireless telegraphy at almost all ocean-coast stations and on most ocean-going ships. On account of its extensive use, it is also known as the ***universal code***. The Continental is much superior for signaling through long submarine cables, and, owing to the fact that it has no spaced letters, such as *c*, *o*, *r* and *y*, that are apt to be taken for two other letters, it is freer from errors of transmission. For instance, with the Morse code, it is very easy for *ee* to be taken for an *o*. On a siphon submarine-cable recorder, it would be practically impossible to avoid such errors. The American, or Morse, code, owing to the fact that there are fewer dashes in it, is about 5 per cent. more rapid than the Continental. However, the Continental is preferable for several reasons, and would doubtless have been adopted in this country if the Morse alphabet had not already obtained such

a stronghold among operators. So far it has been found impossible to get operators to learn a new code.

By comparing the Morse and the Continental codes, it will be seen that the figure *4* and the following fifteen letters *a, b, d, e, g, h, i, k, m, n, s, t, u, v,* and *w* are the same in both; but the numerals, except the figure *4*, the punctuation marks, and the following eleven letters *c, f, j, l, o, p, q, r, x, y,* and *z* are different.

40. Phillips Code of Abbreviations.—Mr. W. P. Phillips's code is a system of abbreviations, or a sort of shorthand applied to telegraphy. It consists of single letters and combinations of two or more letters, which arbitrarily represent figures, words, and whole phrases. Words and phrases that occur most frequently in newspaper reporting are represented by single letters and short combinations of letters; for example,

Q means *on the*
C j means *coroner's jury*
A b m n means *abomination*
C q a s means *closed quiet and steady*
S c o t u s means *Supreme Court of the United States*

This code contains several thousand characters or abbreviations, and, to be able to use it to the best advantage, the press operator must memorize as much of it as possible. As so many abbreviations are used, it is impossible for the receiver to copy the matter in full as fast as it comes over the wire, for which reason, some sort of an ink register is necessary with which to receive the message. Several operators can be kept at work transcribing the despatches from the record on the paper ribbon as fast as it comes in, at the same time making, by some manifold process, a copy for each newspaper interested. A person desirous of engaging in press work, or who cares to study this subject, which is sometimes called *stenotelegraphy*, should obtain the complete Phillips code, which is published in book form.

41. A B C Code.—A very extensive and complete code, arranged for the use of the public, especially for sending

submarine cablegrams, is called the A B C code. By its use, a long message can be transmitted by means of a few words, and the cost of a cable message, which might otherwise be very expensive, can be made quite reasonable. It is published in book form, and both the sender and receiver must have a copy of the same code book, for the telegraph and cable companies will not form or translate the message. By its use, a secret or private code can be very easily arranged. Each page in the book is divided into three columns. In the first column are figures from 1 to 99,999, inclusive; in the second column are words or combinations of letters arranged alphabetically; and in the third column are placed the words, phrases, or sentences that the numbers or words in the first or second column represent. For example, suppose the body of a message to be cabled is as follows: *Tugs now assisting; we write you full particulars,* in which the important words are *tugs* and *write*. Looking these up in the code book, the lines containing them will be found to be:

14,643	*Turtle*	*Tug* (*s*) *now assisting*
15,419	*Worthily*	*I* (*we*) *write you full particulars*

The body of the message may then be written *Turtle Worthily*. The person receiving the cablegram would then look up in his code book the meaning of the two words *turtle* and *worthily* and thus learn the meaning of the message. In this way, instead of eight words, only two have to be transmitted and paid for.

42. Cipher A B C Code.—Any one by using this code, can arrange a secret and private cipher. To do this, he should take ten letters, or, preferably, a ten-letter word in which the same letter does not occur more than once; such as the word *Cumberland*, and number each letter as follows:

c	*u*	*m*	*b*	*e*	*r*	*l*	*a*	*n*	*d*
1	2	3	4	5	6	7	8	9	0

In the first column of the code book, opposite the two phrases "Tug (s) now assisting" and "I (we) write you full particulars," are the two numbers 14,643 and 15,419, respectively. In the word "Cumberland," *c* represents the numeral 1, *u* the numeral 2, *m* the numeral 3, and so on. Thus, the number 14,643 is represented by the group of letters *cbrbm*, and the number 15,419 by *cebcn*. On the message blank, the sender using this cipher code would write, as the body of the message, the two following combinations of letters, for they are not apt to be words, *cbrbm* and *cebcn*.

These letters would be transmitted by the operator, in groups exactly as written, and the person to whom the message was addressed would first translate it into the two numbers 14,643 and 15,419 by means of the private code word "Cumberland" and the numerals corresponding to each letter in this word. Then, by looking up these numbers in the code book, the correct meaning would be obtained. It is evident that only the parties knowing what numeral corresponded to each letter in the code word could interpret the message.

43. If the code runs up to 99,999, that is, five figures, each combination of letters transmitted should contain five letters, and, therefore, if the number contains less than five figures, ciphers must be prefixed to make five figures. This is necessary, to avoid the risk of a wrong grouping of the letters by either the sending or receiving operator. For instance, suppose the word *best* were to be sent. In the code book would be found:

1,734	*Becalming*	*Best*

Now, 1,734 has only four figures in it, but five must be used by prefixing a cipher; thus, 01,734 and the corresponding combination of letters to be sent would be *declmb*.

44. Use of Typewriters.—The typewriter is extensively used for writing down the telegraph messages as the operator receives them from the sounder, and also for transcribing the

messages from the receiving ribbon in the Wheatstone automatic system. A great many operators use it, and the expert manipulation of the typewriter by the receiver is almost a necessity in order to secure employment with the press associations.

A good typewriter can easily write from 60 to 70 words per minute; an expert telegraph operator cannot send steadily with the regular telegraph key over about 40 to 45 words per minute; consequently, the receiver has plenty of time, in addition to writing the message, to insert also the "time received," the "operator's sign," etc., even when receiving at the above fast rate. By means of the Phillips abbreviated code system, the speed of transmission may be raised to 65 or 70 words. The receiving operator must also be an expert typewriter, and such operators are frequently called *typotelegraphers*.

45. In the telegraph tournament held in New York in 1898, typewriters were used in a message-receiving contest. The receiving and recording of messages on typewriters under the great speed used in the contest was quite difficult, owing to the rapid shifting of the machine, combined with the necessarily prompt and proper adjustment of the blanks in the typewriter. An operator, who had in another contest shown himself capable of sending 253½ words in 5 minutes, sent 50 messages in 32 minutes 37 seconds. The winner finished first with 20 imperfections. He filled in the month and year in every case and punctuated completely, and his typewriting was of a very superior character.

As many as 413 words have been typewritten in 4½ minutes, from dictation. But to send 254 words in 5 minutes with the regular key is a more remarkable feat than to typewrite 413 words in the same time. The telegraph sender uses only one hand and has to make many strokes for one letter; the typewriter receiver has the free use of eight fingers, each one of which makes a complete character or letter with a single stroke. This comparison illustrates the necessity of improving the present method of sending if a further increase of speed for manual transmission is to be obtained. The use of mecograph and similar telegraph keys enables an operator to send faster.

TELEGRAPH KEYS

46. The key, as already defined, is an instrument for making and breaking the circuit. Its down stroke is often called the *make*, and its up stroke, the *break*, referring, of course, to the making and breaking of the circuit. The tendency in the United States has been toward a light but strong key. An operator should use a key suited to his style of operating, because by so doing he may be able to increase his speed considerably. The contacts on most good keys are made of platinum, because of the ability of that metal to resist, better than most other metals, the corroding and fusing action of the electric arc that is always formed at the break.

When a key, on rising, does not break the circuit, it is said to *stick*. This sticking may be due to any one of several causes. The principal cause is the fusing action of the electric spark at the contact points, but it may be caused by metallic dust collecting on and bridging over the contact points, or by an improper adjustment that causes the points to come together improperly and bind. The contact points, therefore, should be kept clean by drawing between them a piece of hard, clean paper or fine emery cloth, or they may be rubbed very gently with a very fine file and then wiped clean. Frequent use of the file or emery paper, however, should be avoided.

47. Other troubles are often mistaken by an inexperienced operator for a sticking key. Dirty relay points, for instance, have exactly the same effect on the sounder or the register as a sticking key, and when this is the case the relay contacts should be cleaned with fine emery paper or a very fine file. However, this should not be necessary very often nor done too frequently, for in time the platinum or hard-silver contacts will be worn away.

Pivot screws often become loose and cause trouble; to prevent this they should be kept as tight as is consistent with a free and easy movement of the key.

Loose connections under the table, especially in railroad offices, are frequently the cause of poor and irregular signals.

Leg keys should have legs 2 inches long, have forty well-cut heads to the inch, and have a thumbscrew and two washers for each leg.

48. Bunnell Legless Key.—A form of key extensively used is shown in Fig. 12. It consists of a steel lever *l* and trunnion, all in one piece, and pivoted in trunnion screws *c*, which are mounted in standards projecting upwards from the brass plate *m*. Locknuts *c'* bind the trunnion screws in any position to which they have been adjusted. A coiled spring *u*, which may be adjusted by the screw *y* and secured by the locknut *y'*, presses the forward end of the lever upwards. The upward movement of the forward end of the lever is

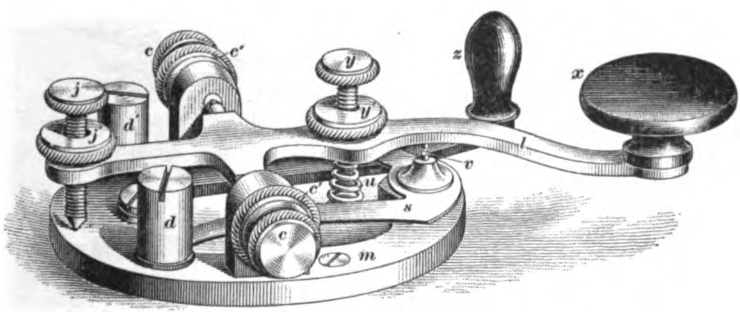


Fig. 12

limited by the screw *j*, and the latter is held securely in position by the locknut *j'*. As the handle, or button *x*, made of insulating material, is pressed down, a platinum contact point *v*, carried on the under side of the lever, makes contact with a point of similar material carried on, but insulated from, the base *m*. This lower contact point, or anvil, is in metallic connection, by means of a flat strip of metal *s*, with the binding post *d*, which is also insulated from the base plate *m*. The other binding post *d'* is connected directly to the base plate. These binding posts *d* and *d'* form the terminals of the key.

49. The path through the instrument may be traced as follows: From the binding post *d*–strip *s*–lower contact point; then, when the key is depressed, to the upper contact point *v*–the trunnion–trunnion screws and spring *u*–base plate

m–binding post *d'*. The switch handle *z* is connected with a metallic arm called the *circuit closer*, pivoted directly on the base *m*, and, when pressed toward the key lever *l*, makes contact with an extension of the strip *s*, thus short-circuiting the key. This circuit closer will be easily recognized as performing the same functions as the switch *C* in Fig. 8. The key shown in Fig. 12 has holes in the base and is fastened to the table by ordinary screws.

50. The Bunnell key is made also with legs similar to those of the Victor key, shown in Fig. 13. Leg keys are fastened to the table by means of the legs, washers, and thumbscrews, and the legs take the place of the binding posts on legless keys.

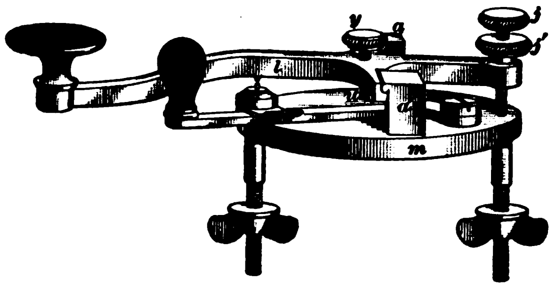


FIG. 13

The wires terminating at the key are clamped between the under side of the table and the thumbscrews. One leg is connected directly to the base and the other passes through the base plate, being insulated from it by hard-rubber bushings, and is connected to the anvil.

51. Victor Key.—In Fig. 13 is shown the Victor key. It has, instead of the trunnion screws used in most keys, two relatively long knife-edge bearings at the junction of the light steel lever *l* and the projections *a*, *a'* from the base plate *m*. The spring *u* is adjusted by the screw *y*. The amount of play, that is, the amount of the up-and-down motion of the lever, is adjusted by the screw *j* and locked by the nut *j'*. The motion is easy and directly up and down, without any side play. The wear on the knife-edge bearings is small, and

what little wear there may be is automatically taken up by the spring *u*. It is claimed that this key will work as true after being used for years as when new. The Western Electric Company owns the patents on Victor telegraph instruments.

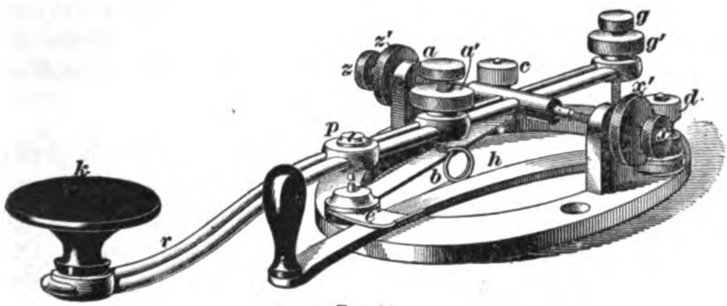


FIG. 14

52. Western Electric Key.—In Fig. 14 is shown the Western Electric key. In this key, the upper platinum point is fastened to the end of the screw *p*, which passes through the lever *r*, so that, if ever necessary, the screw and the platinum contact can be removed and replaced without disturbing the key.

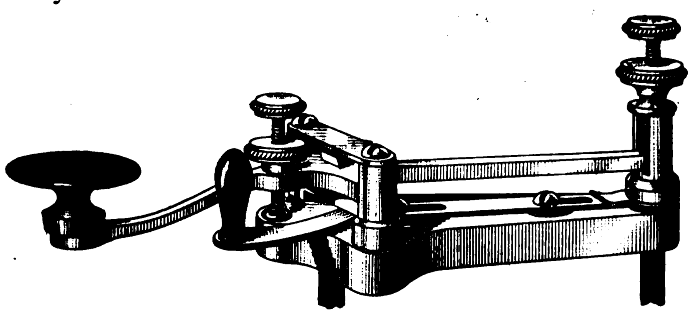


FIG. 15

53. Lefley Key.—In Fig. 15 is shown the key made by S. B. Lefley. The lever works on knife edges instead of on trunnions and screws. The maker claims that the knife-blade hinges eliminate all side motion of the lever and make it necessary to give the key only a very delicate touch, which enables an operator to send faster with it than with any other

key. He also claims that the adjustment is permanent and that the rear-end contact, being the same distance from the knife edge as the key knob, gives a greater opening between contact points and hence produces a clearer break. There is a contact plate on the rear end of the lever, which is claimed to insure a firmer contact than when two small points are used. The lever is thinner at the front end, thereby making it quite resilient and easy on the sender.

54. Bunnell Double-Speed Key.—In Fig. 16 is shown a double-speed legless key made by Bunnell & Company. The key is operated by a sidewise rocking motion of the lever, which it is claimed does not produce cramp of the hand. Two contact points are provided at the ends of adjusting screws *a* and *b*. Spring *c* offers resistance to side motion of the lever, and its tension may be adjusted by moving the clamping block shown at the end of the spring. The block is locked in position by screw *d*. The circuit-breaker is shown at *e*; one terminal of the key, at *f*; and the other, at the top of the lever block. The contact points should be adjusted close together with the key lever normally midway between them, but not touching either. When operating, the lever makes contact in either direction, no two successive contacts being made on the same side. For example, if the dash of letter *D* is made to the right, the first dot is made to the left, and the second dot to the right.

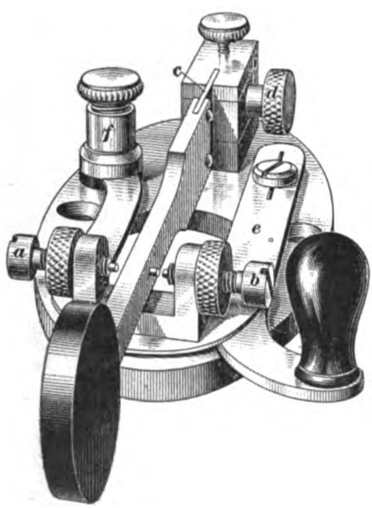


FIG. 16

55. Fry, Open-Circuit, Dry-Battery, Telegraph Key. Mr. U. J. Fry has devised a key to be used in telegraph circuits operated by dry batteries, which are being used in place of

gravity cells by some railroads. In such a circuit, the dry batteries must be left on open circuit when not being used to send signals, but the line circuit containing the relay must at the same time be closed so as to be able to receive signals. The connections are shown in Fig. 17 (*a*), and a view of the key and its connections in (*b*). In order to use the key devised by Mr. Fry, the operators do not have to learn anything new. The movement for throwing open the circuit-closer on the Fry key is the same as for the ordinary key, this movement connecting the battery in series with the line and relay, that is, in a position to transmit signals. The reverse movement, or the closing of the circuit closer, puts the home dry battery on open circuit but leaves the relay in series with the line, that is, in position to receive signals. When the circuit switch is in closed position, the battery circuit cannot be closed by pressing down

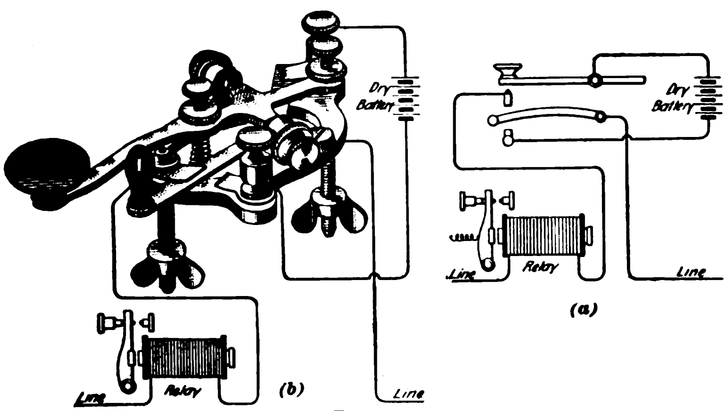


FIG. 17

the key lever, hence there is no danger of wasting the battery by a book or other heavy article resting on the key knob. It is claimed that reliable dry cells are so much cheaper than gravity cells that exhausted ones can be thrown away and replaced by new ones at less expense than for attending and renewing gravity cells. Enough cells must be used, however, at each station to operate the whole line.

56. Twentieth-Century Key.—In Fig. 18 is shown the twentieth-century key with one of its faces removed to show

the interior construction. This key was devised by Mr. Charles Skirley for the use of telegraphers troubled with telegrapher's cramp. It is operated by the handle, which may be set in any position convenient for the hand which grasps it. A soft spring contact is used on the end of the lever *a*, consequently

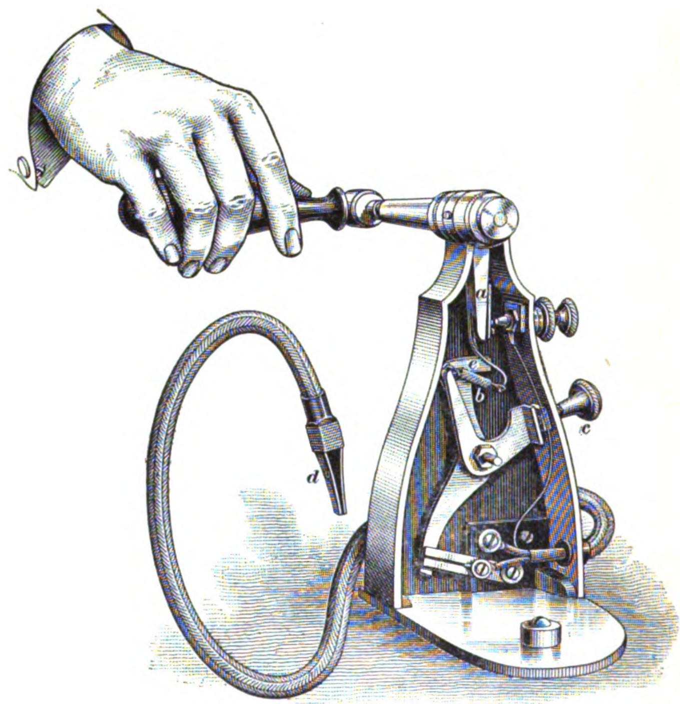


Fig. 18

there is no jar on this key as there is on keys that have solid contacts, and the tension on the lever may be adjusted by means of the spring *b* and the knob *c*. The circuit-breaker is controlled by a knob projecting at the point *e*, from the front of the key, consequently it cannot be shown here. The twentieth-century key is used in combination with the ordinary key by inserting the wedge *d* in the circuit-closer springs of the ordinary key.

57. Mecograph.—An instrument called the mecograph is shown in Fig. 19. The ordinary operation or movement of the key handle *a* causes a pendulum rod with the weight *b* to vibrate uniformly. Pressing the key to the left holds the line circuit closed between contact *d* and adjustable screw *c* and sends a dash of any desired length. Pressing the key to the right allows the pendulum to vibrate and alternately close and open the line circuit between the long spring *f* and adjustable screw *e*, thus making dots all the time the key is so held. To make the letter *b*, for instance, the key is moved to the left and held there for the length of time necessary to make the dash, and is then moved to the right and held there

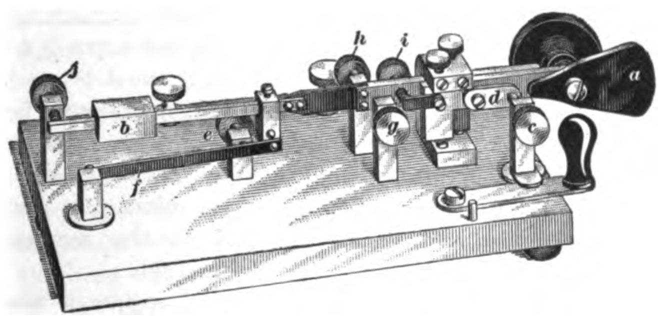


FIG. 19

until the vibrating lever has automatically made the three dots required. In sending the letter *p*, which consists of five dots, no more labor is expended than in transmitting the letter *e*, which consists of only one dot. The parts are made interchangeable and the mecograph can be adjusted for fast or slow sending and for light or heavy signals.

58. The following instructions are issued by the makers for the use of the mecograph and should be carefully followed when making adjustments: It is very important not to grip the key. Rest the hand or the elbow on the table and tap the key to the right, holding it in that position until the required number of dots has been made; tap it to the left for dashes, holding it in that position until a dash of suitable length has been made. Leave a space between the thumb and dot key

on the left side and the fingers and dash key on the right side. Make all dots, whether one or more, on the dot side. Increase speed by sliding hammer *b* to the right. Slide it to the left to decrease speed. This hammer will stay wherever it is put. Make dots heavier by turning thumbscrew *e* out. Turn it in to make them lighter. This screw, if turned in too far, separates contact points entirely; if too far out, it does not separate them at all. Avoid both extremes.

The distance through which the bar is allowed to move is regulated by thumbscrews *g* and *h*. Screws *j* and *h*, when properly adjusted, should touch and stop the bar and vibrating rod about simultaneously. When lengthening the stroke by turning out screw *g*, a corresponding change must be made in thumbscrew *e*. Instruments, before leaving the factory, are adjusted to suit the average operator, and will seldom, if ever, need any further change, except in the manner of speed and dot weight.

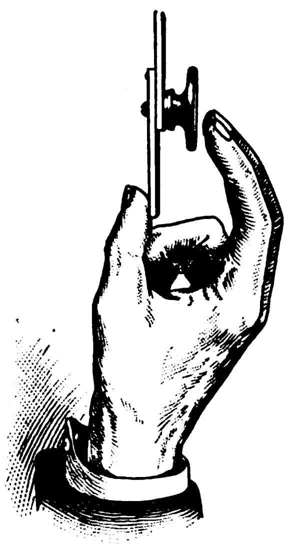


FIG. 20

Thumbscrew *i* regulates tension on dash and dot arms alike. Turn in to increase tension; out to decrease it. Thumbscrew *c* regulates the distance desired between dash-contact points. Never take a screw out of its post.

59. A free arm movement should be used. Do not try to operate the lever with merely a finger movement; the arm is stronger and quicker. Use the tips of the thumb and the tips of the first two fingers, as shown in Fig. 20. Never grip the key. When pressing the lever to the dot side there should be a space between the key and fingers, as shown; likewise, when moving the lever to the dash side, a space should be left between the key and the thumb. Rest the elbow on the table and send deliberately; do not try to rush through words.

Make plenty of space between letters and words and make dashes of ample length. The beginner should make more space and longer dashes than is really necessary, as this gives time to think how to form the next letter and tends to prevent failure. Speed will be acquired if this rule is followed. If any trouble is experienced in making the letter *v* or the figures *3* and *4*, simply make *st* for *v*, *sn* for *3*, and *hl* for *4*. Practice will enable one to make the dots and dashes properly. An operator who has lost his ability to send because of telegrapher's cramp can do acceptable work with the mecograph, as he can send about as fast as the receiving operator can write the message with a typewriter. There are other vibrating keys on the market employing the same general principles but differing in construction.

60. Preventable Faults of Vibrating Keys.—If properly handled, vibratory transmitting devices add great capacity to the line wire with which they are used; if they are carelessly used they are inefficient. For instance, if even a good machine sender replaces a hand sender on a long duplex circuit that has been working smoothly, the probability is that the receiver will break and interrupt the message to complain that the signals are too light. Before the trouble can be remedied there will have been lost enough time to have permitted the exchange of many messages by hand transmission with the ordinary telegraph key, and probably 10 per cent. more by machine transmission.

The cause of the light signals is due, generally, to too great a mechanical inertia of one or more parts of the multiplex apparatus and not to the sending device itself. Each operator should be properly informed, and in the case of light signals the receiver should lessen the play of his sounder lever. This one adjustment will usually prevent further delay if the home and repeater-station apparatus are in proper adjustment. If, on the other hand, the readjustment of the sounder, although helpful, fails to remedy the trouble, the sender should request the man in charge of the apparatus to readjust the pole changer in the home quadruplex or duplex set. The repeating station

should be called in as a last resort, as the fault is least likely to be found at that place.

A machine sender should be careful not to injure the circuit closer of the Morse key when he inserts his cord wedge, as the thick wedge is apt to raise the thin upper contact so high that when the Morse circuit closer lever is turned to close the key circuit the latter is left open or very loose, and the fault may not be discovered promptly; there is thus another delay, due to carelessness of the machine sender. Furthermore, the conducting cords wear out in time and frequently cause temporary openings or high resistance in the circuit, due to broken strands, often long before the fact is recognized by an unobserving operator.

ELEMENTARY TELEGRAPHY

(PART 2)

TELEGRAPH INSTRUMENTS

TELEGRAPH RELAYS

DESCRIPTION OF RELAYS

1. A telegraph relay consists of an electromagnet that, by its action on an iron armature, opens and closes the circuit of a local battery powerful enough to operate a sounder or register. The magnet is generally wound with a large number of turns of insulated copper wire in order to enable the feeble line current usually employed to produce in the cores a magnetization sufficient to attract the armature. But, in order to get the large number of turns necessary in the space allowed, fine wire must be used, and hence the relay will usually have a resistance high in comparison with that of a local sounder.

2. Relay Contacts.—The contact points, between which the circuit is made and broken, should be made of platinum or hard commercially-pure silver, in order to resist the corroding and fusing action of the electric arc that is formed when the contact points separate and break the current. Some prefer hard silver for all contacts, except on keys, because the silver soon oxidizes and, it is claimed, becomes a better conductor than before. It is also much cheaper than platinum, the price of which seems to be constantly increasing.

§ 13

The contact screw next to the coils at which the circuit is opened and closed is called the *front stop;* the other screw, against which the armature is pulled by the retracting spring when no current flows through the relay coils, is called the *back stop.* The point of the rear, or back, stop-screw is made of insulating material, or else the whole screw must be insulated from the supporting frame.

3. Relay Armature.—The armature and lever, that is, the entire moving part of a relay, should be made as light in weight as is consistent with the rigidity required, in order to make its inertia as small as possible. The less inertia possessed by the moving parts, the more promptly will the circuit be

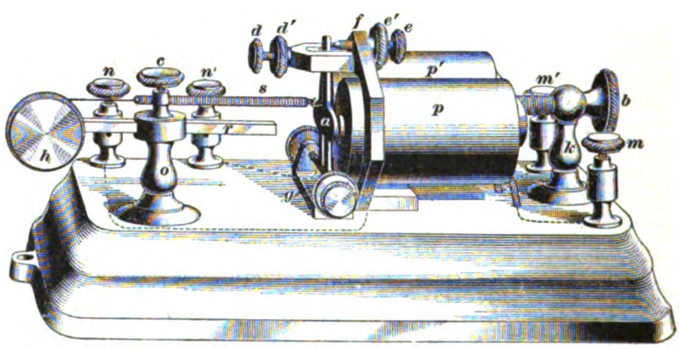


FIG. 1

opened and closed, causing the signals to be made more distinctly and with less danger of their running together when the current is feeble or the speed of transmission especially rapid. Some armature levers are made light in weight by making both the lever and the armature out of one piece of iron, using a good quality of soft iron, and no more of it than is absolutely necessary. On account of its extreme light weight aluminum has been used in place of brass for the levers of relays that are made with an iron armature fastened to a lever of other metal. Some prefer armatures stamped from one piece of soft iron, reinforced if necessary with brass strips, claiming that aluminum, to be strong enough, must be too bulky.

4. Bunnell Relay.—The main-line relay manufactured by Bunnell & Company is shown in Fig. 1. The electromagnet consists of two soft-iron cores on which are the coils *p* and *p'*, the cores being connected together at the rear by a soft-iron yoke piece. To this yoke piece is attached one end of the screw *b*, by means of which the electromagnet can be moved backwards or forwards. This screw *b* is supported by the pillar *k*. The cores of the electromagnet are arranged to slide easily through the coils and the supporting frame *f*, which is securely fastened to the wooden base. This frame *f* also carries the adjusting stop-screws *e* and *d* and their locknuts *e'* and *d'*.

The armature *a* and lever is made out of one piece of soft iron. It is pivoted between trunnion screws supported by the brass piece *g*, which is fastened to the wooden base, but insulated by the wooden base from the supporting frame *f*. The trunnion screws are provided with locknuts, so that, after being once adjusted, they can be securely locked in place. One end of the retracting spring *s* is attached to the armature *a*; the other end is fastened to a piece of silk cord. The other end of the cord is fastened and wrapped around the adjusting screw *h*. This screw *h* passes through one end of the rod *r*, which slides easily through the pillar *o*, but is secured in any position by the setscrew *c*. By turning the screw *h*, the thread is wound or unwound, thus increasing or decreasing the pull of the spring *s* on the armature. When the thread is all wound up and the end of the spring reaches the screw, the screw and rod *r* should be moved out away from the armature. The spring must never be wound up around the screw; many springs are spoiled by doing this.

5. The front stop-screw *e* should be so fixed that, when the armature is against it, there is at least the thickness of a piece of ordinary writing paper between the iron armature and iron cores. The back stop-screw *d* should be adjusted so that the armature shall not have over $\frac{1}{32}$ inch play. The tip of the back stop-screw contains a piece of hard rubber or other insulating material, so that the armature cannot close the local circuit through the screw *d* to the frame *f*.

As the main lines are connected to the binding posts *m* and *m'*, they are called the ***main-line binding posts***. One end of the coil *p* is connected underneath the wooden base with the binding post *m*, the other end is connected to one end of the coil *p'*, and the other end of this coil *p'* is connected underneath the base with the binding post *m'*. The coils *p* and *p'* are enclosed and protected by polished hard-rubber casings. In all cases they should be connected in series with each other, with the windings in such a direction around the iron cores that the front end of one iron core has north polarity and the front end of the other iron core has south polarity. All telegraph electromagnets are generally connected in this manner, and, unless specially stated to be different, they will be assumed to be so connected.

6. The binding posts *n* and *n'* are called the ***local binding posts***, because they are connected with the local battery and sounder circuit. The binding post *n* is connected underneath the base through the brass frame *f* to the front stop-screw *e*; the other post *n'* is connected with the metal piece *g*, which is insulated from the frame *f*, and through a fine wire spiral with the armature *a*. Consequently, when the magnet draws the armature against the front stop-screw *e*, the local circuit is closed at that point. This screw *e* and the end of the armature, which comes into contact with it, are both tipped with a piece of platinum or hard silver. The base is made of polished hardwood, with an under rim of metal. The connections made under the wooden base are indicated by the dotted lines.

In 1912 Bunnell & Company put forth a relay, called the champion quick-adjustment relay. The magnets may be very quickly moved any desired distance from the armature. The sliding arrangement *h r* of the relay shown in Fig. 1 is eliminated and the spring *s* is adjusted in the same manner as on a pony relay. The relay is mounted on a slate base, instead of wood, the surbase measuring 7½ inches by 3½ inches. In place of binding posts, Western Union clamp connections, having machine screws and washers, are used. The connections between various parts of the relay and the clamps are

soldered and the external connections may be securely fastened with a screwdriver under the screw heads. An automatic stop prevents contact between the magnet cores and the armature. The relay is regularly furnished with hardened-silver contact points as adopted by the Western Union and Postal Telegraph-Cable Companies.

7. **Improved Western Union Relay.**—The relay shown in Fig. 2 is used by the Western Union Telegraph Company and by many railroad companies. About the only difference between it and the Bunnell relay consists in the armature

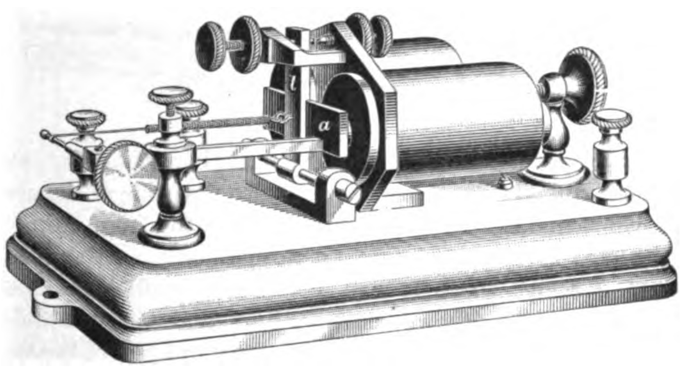


Fig. 2

lever. The Western Union relay has a lever l made of aluminum or brass, to which is fastened the soft-iron armature a.

In the older style relays, called the *standard relays*, it was specified that all four binding posts should be placed in a row along one side, so that many relays of this type will be found in use today. However, as there is no particular advantage in this, it is no longer required nor followed by the manufacturers in their later relays. All main-line relays differ so little in construction that one description practically applies to all.

8. **Pony Relay.**—The **pony relay** is somewhat smaller than a main-line relay, and differs from the latter only in size and details of construction. A pony relay, representative of its type, is shown in Fig. 3. This has a one-piece iron armature and lever, adjustable front and back stop-screws with

locknuts, an arrangement for adjusting the armature retracting spring, and a mahogany-wood base with a metal rim. This relay is 6½ inches long by 3½ inches wide. The rear stop-screw *c*

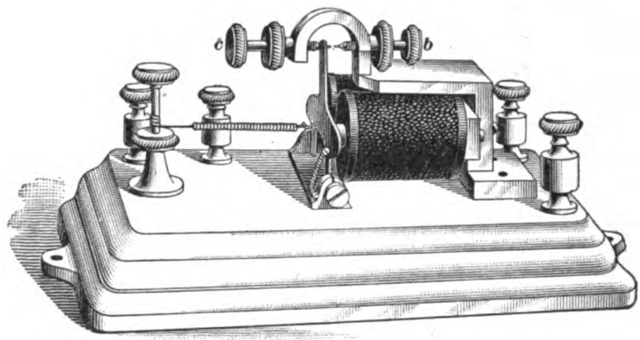


FIG. 3

has an insulating end made of hard rubber, the front stop-screw *b* is tipped with platinum, as is also that side of the armature which makes and breaks contact with the front stop.

Although it has not so many adjustments as the regular main-line relay, those it has are usually sufficient. These relays are used for private telegraph lines, and may be obtained wound as high as 100 ohms, but they are more generally wound to have resistances of 20, 40, and 75 ohms. A 100-ohm pony relay is suitable for a line 50 to 75 miles long.

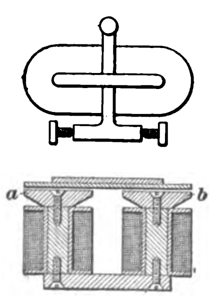


FIG. 4

9. Enlarged Pole Pieces.—Mr. F. F. Fowle claims that he has experimentally proved that a substantial increase in the pull of a relay is secured by increasing the area of the air gaps. The practical benefit that results from this departure in the construction of the magnetic circuit is the ability to reduce the ampere-turns and the resistance, without sacrificing the intensity of the armature pull now obtained. There are various ways of securing this result, one of which consists in adding enlarged pole pieces *a* and *b*, Fig. 4, to a standard telegraph relay. A superior design, he says, is the

iron-clad type of magnet, shown in Fig. 5, which has a large pole piece *a* on a central core. With this construction a total pull of no less than the pull in a standard 150-ohm relay can be obtained with not more than a 20-ohm winding. This construction tends to require heavier armatures, but by using

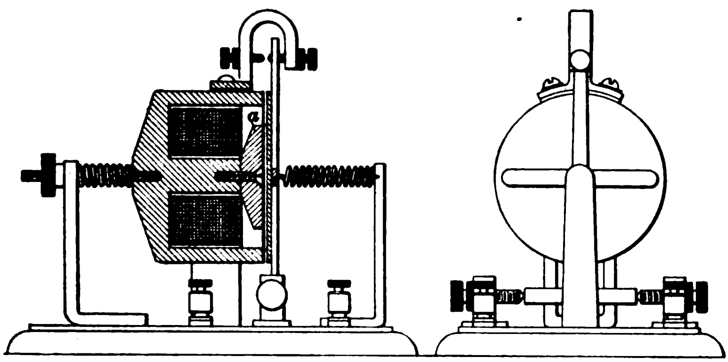


FIG. 5

iron armatures as thin as practicable, mounted on aluminum frames, a 35-ohm relay can have its resistance reduced to 20 ohms. The use of such relays on railroad telegraph way circuits produces especially marked improvement.

ADJUSTMENT OF RELAYS

10. The front and back stops must be adjusted so that the armature of the relay shall not move more than $\frac{1}{32}$ inch; and, when the movement of the lever is very feeble, the distance should be made as small as possible. Under ordinary circumstances, this adjustment scarcely ever needs alteration after it has once been made correctly. The armature should never touch the iron cores; otherwise, it will stick against them when the current is broken, on account of the residual magnetism remaining in the cores. There should always be room enough between the iron armature and the cores to insert one thickness of ordinary writing paper.

11. To adjust a new relay, screw the magnet cores almost as far forwards as they will go. Adjust the front contact screw so that when the armature is against it there shall be the thickness of an ordinary piece of writing paper between the armature and the cores. Adjust the back stop-screw to allow the armature a play not to exceed $\frac{1}{32}$ inch. Finally, adjust the spring so that the normal current, when sent through the coils, will promptly pull the armature against the front stop, and so that the spring will as promptly pull the armature away when the current ceases. It will be necessary to readjust the position of the iron cores and even the tension of the spring from time to time as the current strength varies.

A retractile spring not possessing closely fitting coils is not capable of following the minute fluctuations in magnetic strength that take place in very wet weather at way stations remote from the battery. The spring must possess great elasticity and for best results the tension should be very slight, just enough to keep it taut, and it should be kept that way regardless of the weather or strength of current through the relay coils. If possible all readjustments should be made by moving the magnet and the spring tension not altered except to give the final touch.

12. Effect of Leakage on Adjustment.—During wet weather, on badly working wires, a relay often remains still when a distant office is sending. In such cases, it is necessary to adjust *high*, that is, to move the cores farther back or to make the tension of the spring high or strong, or both, in order to get signals from such stations. Especially is this the case on lines on which the battery is divided, part of it being at each end. As most long lines are so arranged, it may occur quite frequently on them. This trouble is caused by the leaking or escaping of current from the wire through the insulators and poles that are between the sending office and the office where the relay fails to respond. In rainy weather, this leakage may be considerable, and it may act the same as if some intermediate office had grounded the wire.

9

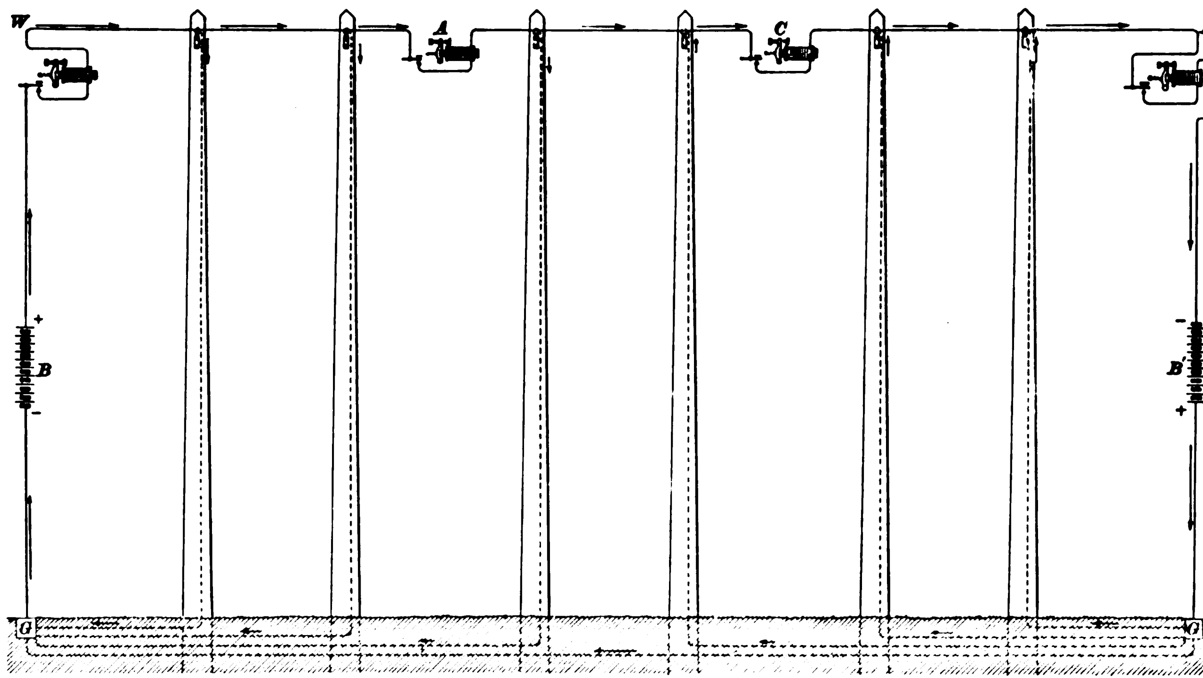


FIG. 6

In Fig. 6, let W and E represent terminal offices, and A and C intermediate offices on a long line having one-half the total number of cells at each end. The dotted lines represent the paths down the poles to the ground and back to the batteries along which the leakage currents flow, and the arrows indicate the direction in which the current flows. If the leakage is very bad, very little of the total current from the battery B will reach the farther intermediate station C and still less will reach the terminal station E. Similarly, very little current from the battery B' will reach the intermediate station A and still less will reach the terminal W. However, the current flowing, from both batteries B and B', through the relays at the terminals W and E will be stronger than if there were less or no leakage. The current through the intermediate stations A and C will be smaller, and perhaps much smaller than the current at either terminal W or E. The relative values of the currents along the various paths, when all the keys are closed, are shown approximately by the lengths of the arrows.

13. Under the conditions shown in Fig. 6, the operation of the key at one terminal station E will cause the relay at that station E to work vigorously, the relay at the first intermediate station C to work less vigorously, that at the other intermediate station A to work still less vigorously, and the relay at the other terminal W to work even less vigorously than the relay at A. The same thing will happen in the reverse direction when the key at the other terminal W is operated. When an intermediate key is operated, only a part of the current that flows through one end relay is interrupted, and the relay at one end, as W, will respond less and less vigorously the farther off the sending office is from that end W. When a key far distant from the terminal W is open, the current at the terminal W may be sufficient to make the relay hold its armature if the adjusting spring is at its usual tension.

This effect on a relay can evidently occur in either direction when a battery is placed at both ends, but only in one direction when the battery is all at one end. If there is a battery

at one end only, opening a key at any office will cut off all the current, whether it is large or small, from the entire line on the side of the key away from the battery, and the armatures of all relays beyond will be released. Sometimes, therefore, on hard-working lines, where there is much escape on account of a rain storm, it is advantageous to take the battery off at one end, ground that end, and work with a battery at one end only.

14. Determination in Wet Weather of Use of Line. The key should never be opened in order to call an office on an apparently idle circuit during wet weather, until it has been ascertained whether another office is using the wire. The relay may be out of adjustment and, therefore, may fail to indicate that the line is in use. The best way to determine whether some one is using the wire, is to place a finger lightly on the armature lever of the relay and gently move it away from the contact point, that is, away from the cores of the magnet. If some one is sending, the signals will be at once heard or will be felt by the finger.

15. Adjustment of Relay in Wet Weather.—If it is evident that some one on the line is sending, and the operator wishes to receive the message, he should screw the magnet cores away from the armature until the relay stands open. He should then turn down or weaken the retractile spring until the signals can be easily read. Care should be taken not to weaken the spring too much, for the signals may be shut out entirely. In rainy weather, it is much better to move the magnet away from the armature than to make the retractile spring too stiff. A weak spring is more sensitive than a stiff one. Whenever possible, the relay should be adjusted for the most distant office on the circuit, because, as a rule, it will then be adjusted for all intervening stations.

RELAY QUICKENERS

16. American Telephone and Telegraph Relay Quickener.—An operator working with an ordinary relay, key, and sounder on a *composite wire*, that is, a line through

which both telegraph and telephone messages are transmitted at the same time, generally complains of the poorness of the circuit because he has to adjust high to hear the distant offices on account of the large amount of artificial capacity caused by the use of condensers in the circuit. With the relay adjusted high, it is always hard for an operator to hear distinctly his own signals. To overcome this a **relay quickener** was devised by the engineering force of the American Telephone and Telegraph Company. It consists, as shown in Fig. 7, simply in bridging the key and relay with a 4-microfarad condenser in series with sufficient non-inductive resistance to so time the discharge of the condenser as to just sufficiently assist in the closing of the home relay when the home key is closed. For a standard 150-ohm relay the proper amount of non-inductive resistance is 400 ohms. When the key is opened the condenser is charged by the line potential and when the key is closed the condenser discharges through the relay, key, and 400-ohm non-inductive resistance. The whole success of this arrangement depends on having just the proper amount of non-inductive resistance to suit the design of relay used. Even on an ordinary telegraph wire these quickeners are of great benefit in heavy weather.

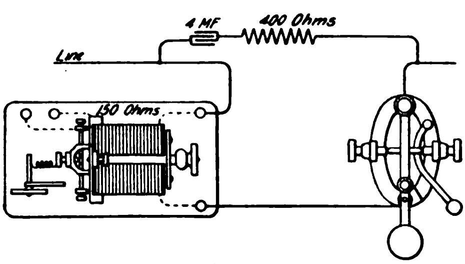


FIG. 7

17. Field's Relay Quickener.—When a relay works sluggish or drags, the sending operator usually complains that his relay is not receiving enough current. More current livens up his relay, but causes more line leakage and discomfort to the man at the distant station. To eliminate this demand for more current and higher potentials which are not always necessary or desirable, Mr. Stephen D. Field suggests the arrangement shown in Fig. 8. For sending, the key switch *e* must be

arranged to rest on a point *c* that is connected through a condenser *f* and an extra 5,000-ohm winding *a* on the relay to line *1*; for receiving, the switch *e* rests on the regular point *d* that is connected with the usual 150-ohm winding *b*.

With the switch *e* resting on the sending contact *c* and the key *k* open, no current is flowing in either coil *a* or *b*, but the condenser *f* is charged to the full potential of the batteries because the line is practically open at *f*. Assuming that line *1* runs to the positive terminal of the main-line battery, the side of the condenser connected to the coil *a* has a full positive charge. When the key *k* is closed, the condenser partly discharges because the potential across its terminals is reduced to that now existing across the 150-ohm coil *b*. This discharge passes through *a–b–k–h–e–c–f*, as indicated by the arrowheads, thereby building up the magnetism of the relay quicker than the main-line current, which is also commencing to flow through coil *b*, can do so alone. When the key *k* is released, the circuit through coil *b* is not only opened, but the full main-line potential is applied to the condenser, thereby causing it to receive a greater charge, the electricity flowing from *g* through the coil *a* in a direction that tends to reverse the magnetism of the relay. Consequently, the magnetism is very quickly reduced to about zero. Hence, this relay should magnetize and demagnetize, no matter how high the adjustment of the spring tension may be, more quickly than the regular relay, and thus possibly reduce the prevalent demand for a little more current.

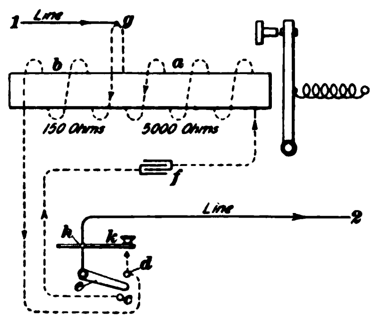


FIG. 8

TELEGRAPH SOUNDERS

DESCRIPTION OF SOUNDERS

18. A **telegraph sounder** is used to give a louder and clearer click than can be obtained with a relay. For this reason it has a strong electromagnet. Its armature and lever, also, are usually quite massive compared with the similar parts of a relay. Sounders are made in a variety of forms but all are the same in principle. Aluminum has been used for various parts, especially for the moving parts of the levers that do not have to be made of iron. The Postal Telegraph-Cable Company, however, has abandoned its aluminum-lever sounders. It claims that these instruments are unsatisfactory because to get sufficient strength in the lever it was necessary to use so much aluminum that there was no gain. It is now using, wherever possible, armatures stamped from one piece of soft iron, which, when necessary, are reinforced with brass strips.

The sounder to be used in any particular instance will depend on circumstances. Some operators can more readily distinguish a light sound than a heavier one, and vice versa. When the sounder is used with gravity cells, in a local circuit controlled by a relay, it is generally wound to have a resistance of 4 ohms, and to 20 or 40 ohms when it is put directly in series with the main-line circuit, in which case it is called a *main-line sounder*. But in all cases, the sounders should be firmly screwed down to the table.

19. Bunnell Sounder.—The **Bunnell sounder,** shown in Fig. 9, consists of an electromagnet, over the two iron cores of which are wound the coils *m* and *m'*, and an armature *a* of soft iron. The latter is mounted on a brass or aluminum lever *l*, which is pivoted between the trunnion screws *k*. The armature is normally held in its upper position by means of the compression spring *s*, which bears down on the short end of the lever *l*, the compression of the spring being regulated by the thumbscrew *h* and locked, after adjustment, by the

locknut h'. The down stroke of the lever is limited by the lower end of the screw g striking against the anvil n; and the up stroke is limited by the lever striking against the lower end of the screw f. The play of the armature can therefore be adjusted by means of the screws f and g, and, after the proper adjustment is obtained, it can be made permanent by the locknuts f' and g'. The binding posts b form the terminals of the circuit through the coils, the current passing through them in series so as to make the upper pole of one iron core have north polarity and the upper pole of the other core have south polarity. The sounds given out by the sounder may be

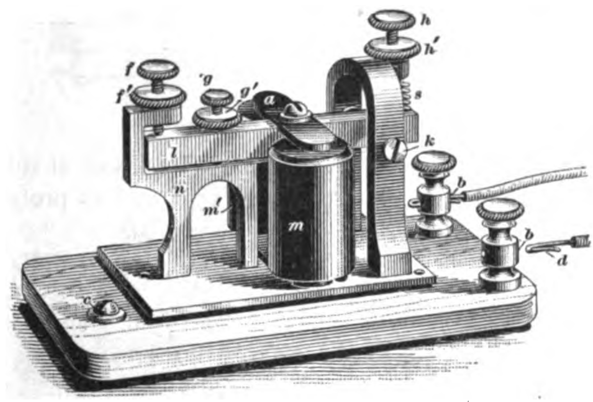


FIG. 9

augmented by mounting the instrument on a sounding board. The metal plate and the wooden base are usually constructed with this idea in view, and, for this reason, are slightly separated. The coils are covered and protected by a polished hard-rubber casing.

20. Improved Bunnell Sounder.—The improved Bunnell sounder, shown in Fig. 10, is in many respects exactly like that shown in Fig. 9. In the improved sounder, however, the usual metallic resonator plate e is supported at three points, only two of which are shown, on a second resonator plate c made of thin wood not over $\frac{3}{8}$ inch thick. This wooden plate, which is very thin and sonorous, is supported and protected

by a second base plate *d* of metal, preferably of aluminum, because the latter is light. This aluminum plate, which carries the weight of the entire instrument, is supported on three

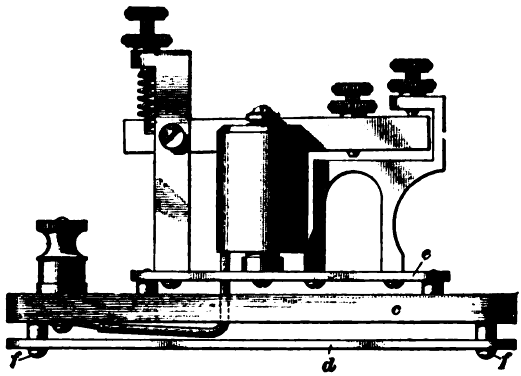


Fig. 10

points, though only two *f* are shown. The object of this construction is to increase the sonorous effect and to protect the thin wooden base.

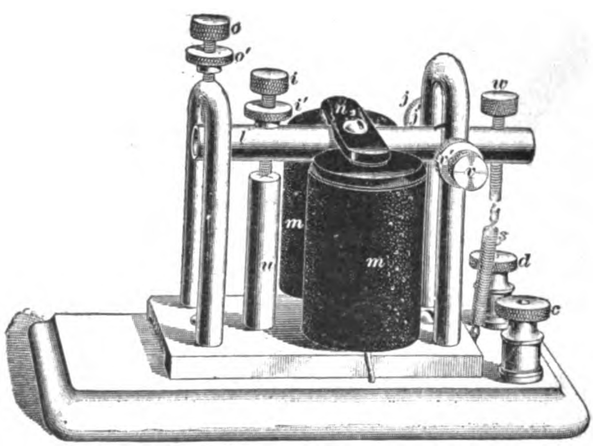


Fig. 11

21. Western Electric Sounder.—The sounder shown in Fig. 11 is made by the Western Electric Company and is extensively used by the Western Union and other telegraph

companies. It has a retractile spring instead of a compression spring as used in the Bunnell sounders. The tension of this spring *s* is adjusted by the screw *w*. The lever *l* and the upright pieces are made of brass tubing, and the coils *m* are covered and protected, as is usual in all well-made telegraph instruments, by a polished hard-rubber casing.

22. M. C. M. Sounder.—In Fig. 12 is shown an improved sounder made by Bunnell & Company. The distance between the iron cores and armature can be very quickly adjusted by an eccentric movement controlled by the adjusting nut *a*,

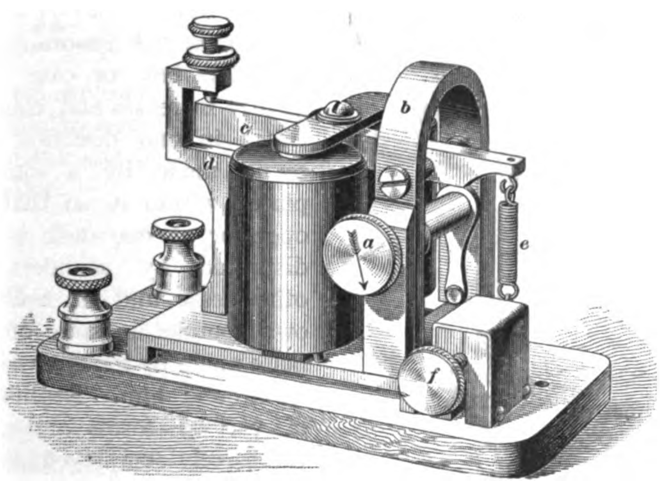


FIG. 12

whereby the arch *b*, in which the lever *c* is pivoted, is made to slide up or down. When the indicating arrow on nut *a* points straight downwards, the armature is as close as possible to the cores, but the armature and cores can never come into actual contact. The position of the arrow is an indication of the relative position of the armature and iron cores. The screw and check-nut ordinarily used on the front end of the lever are dispensed with, simply a steel pin being inserted in the lower side of the lever *c* to strike the anvil *d*. A long and quick range of adjustment of the retractile spring *e* is secured by

means of a cam-lever operated by the lower adjusting nut *f*. Thus, both adjustments are on the front of the instrument where most convenient. The instrument is furnished with either a brass or aluminum lever, with or without a key on the same base, and with full-sized relay coils that may be wound to 50 or 150 ohms, or any other desired resistance. It forms a good main-line sounder, has both magnet and lever adjustments, and is said to give fully three times the volume of sound produced by the very best box relay.

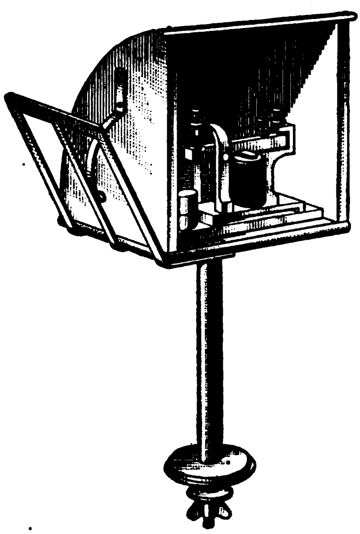


Fig. 13

23. Resonators for Sounders.—A **resonator** is a hollow box or case that greatly increases and concentrates in one direction the sound made by a sounder placed within it, so that an operator at one desk is not disturbed by sounders at other desks, and can hear his own sounder in spite of the noise made by the typewriters all around him. Resonators of various forms are quite extensively employed, especially in large telegraph offices. An adjustable resonator is shown in Fig. 13. The tops, or hoods, of the resonators of this type are removable and have a play of half a circle. The top is made of a hard fiber, the frame being of hardwood. They are fastened to the table by means of a wing nut or thumbscrew underneath the table. As the metal is separated from the table by soft-rubber washers on each side of the hole and a soft-rubber bushing in the hole, no vibration passes from the sounder to the table. The resonator with the sounder encased in it may be turned, after being secured to the table, to the right or left, to suit the convenience of the receiving operator. The wires

connecting the sounder pass through the hollow supporting stem. On one side of the resonator is a clip for holding the blanks upon which the messages are written. Where type-

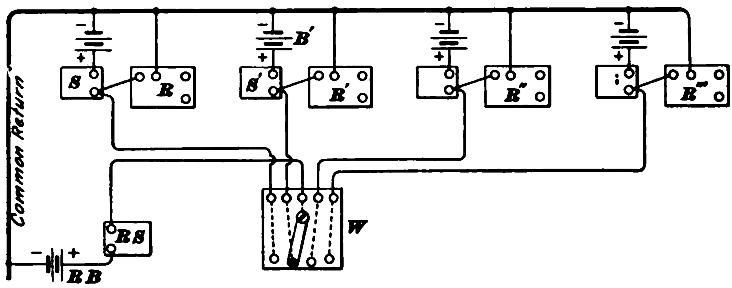


Fig. 14

writers are used by the receiving operators, the resonators are usually mounted upon a swinging extension arm so that the resonator can be swung around and extended to any desirable position.

AUXILIARY SOUNDER CIRCUITS

24. Battery Circuit.—In Fig. 14 is shown an arrangement for connecting a single resonator sounder *RS* to any relay on a table by means of a switch *W*. This arrangement is well adapted for the smaller railroad offices where one man from one position watches all the wires in the office. In the position of the switch shown, the resonator sounder *RS* and its battery *RB* form a circuit in parallel with the sounder *S'* and its battery *B'*, both circuits being controlled by the relay *R'*. As it is necessary to

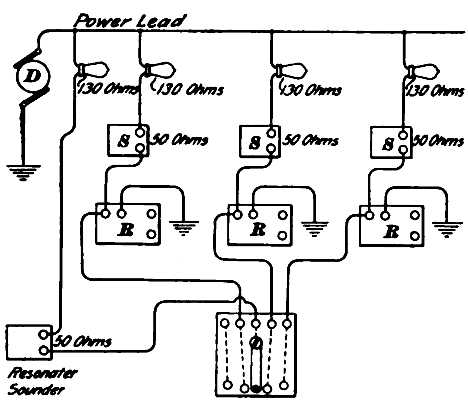


Fig. 15

connect similar terminals of all the batteries to the common return, usually all the zinc, or negative, terminals of the sounder batteries are connected to this circuit. Consequently, when the relay is open, the copper or positive terminal of the battery B' is connected to the copper of the resonator-sounder battery RB and there is no tendency for current to flow provided the batteries are approximately equal in voltage.

25. Dynamo Circuit.—In Fig. 15 is shown a similar arrangement where the sounders are all supplied with current from a 24-volt dynamo D. The sounders have a resistance of 50 ohms and a non-inductive resistance of 130 ohms is included in series with each sounder.

ADJUSTMENT OF SOUNDERS

26. The sounder has three adjustments: one by which the distance of the armature from the magnet cores is regulated, one by which the play of the armature lever is regulated, and one that determines the degree of tension of the retractile spring. To adjust a sounder, the armature lever should be made to work easily and yet snugly on its pivots, which are then locked by their locknuts. Then, the screw limiting the downward movement should be adjusted and locked by its setscrew so that there is room enough between the armature and the cores to pass without catching one thickness of ordinary writing paper. The armature must never touch the cores, for, if it does, it is liable to stick on account of the residual magnetism left in the cores when the current is broken. The screw limiting the up stroke is then adjusted and locked by its setscrew, so as to give the proper length of stroke, which is about $\frac{1}{16}$ inch. Finally, the spring is adjusted so that when the current is interrupted the lever is pulled promptly back against its back stop-screw. If the action of the magnet is very strong and the armature does not move away promptly when released, the tension of the spring must be increased. It may be necessary to screw up the front, or downward, limiting screw a little, in order to prevent the armature from coming too near the cores

when attracted. But when this adjustment has once been properly made it seldom requires any alteration.

27. When the sounder is properly adjusted and gives a satisfactory sound, it should be let alone. If it has worked well for a long time, but at length, in consequence of residual magnetism in the cores, the armature is not properly released when the current is interrupted, the wires coming to its binding posts should be reversed, thus reversing the magnetism. Confusion of signals on the sounder is evidence that the relay needs adjustment. In this case, the cores of the relay magnets should be moved nearer the armature when the current through the relay is feeble, and farther away when it is strong.

28. In cases where the sounder does not act, although the relay responds to a current in the line, there is some fault in the local circuit. The relay points should be closed with the fingers; if the sounder still does not respond, the condition of the relay points and the connections should be carefully looked after, and the electromotive force of the local batteries tested with a millivoltmeter, or it should be otherwise ascertained if they come up to the standard requirements. If the batteries and relay points are all right and the sounder cannot be made to respond by closing the relay points, the trouble is in the magnets of the sounder, in a bad joint, broken wire, or loose binding post. The binding posts of all instruments should be gone over frequently and regularly to insure that none of them are loose.

COMBINATION SETS

29. Pocket Relay.—The **pocket relay,** shown in Fig. 16, is a main-line sounding relay and key that is made in a very compact and convenient form for carrying in the pocket. It generally has a case for enclosing the whole instrument when not in use. It is about 6 inches long, 3 inches wide, and 2½ inches deep. It has all the adjustments of a relay, and gives a sufficiently loud sound for the temporary use for which it is intended. It has two binding posts by which it can be

connected directly in series with the line wire. The construction is shown sufficiently well so as to need no further description. This relay is used for testing out on the road when

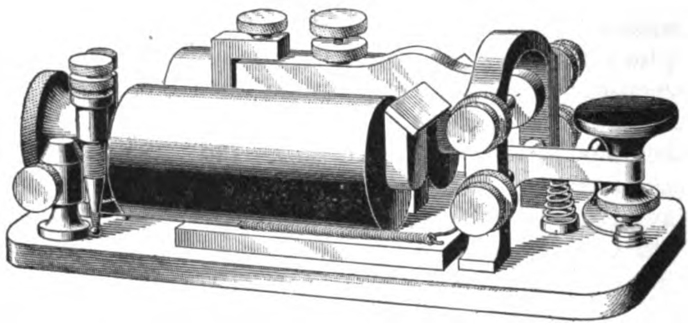


FIG. 16

repairing breaks and crosses, and also by the railroad companies in establishing a temporary office at a point where an accident has blocked the track.

30. Barclay Box Relay.—In Fig. 17 is shown the **Barclay box relay,** which is claimed to be quite an improvement over the older style of sounding-box relay. The thin wood sounding box covers only the ends of the cores of a main-line relay and not the coils and yoke as in the older style. The

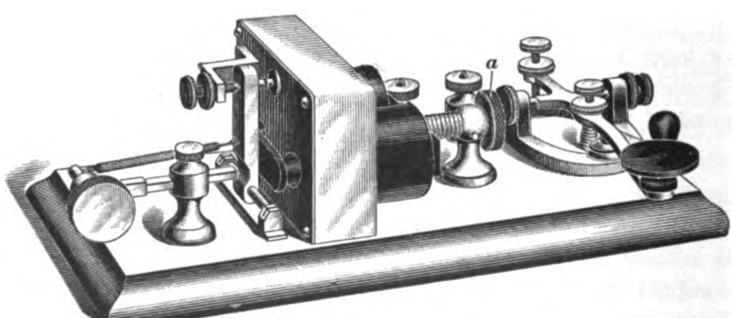


FIG. 17

box, acting as a resonator, causes the relay to give forth sounds clear and loud enough to be read without requiring the use of a sounder. The ends of the cores project slightly, and slide

easily through holes in the left-hand end of the box, and their position may be adjusted, forwards and backwards, as in a main-line relay, by the thumbscrew *a*. The box relay has all the binding posts, contacts, and adjustments of an ordinary relay and is mounted on the same base with an ordinary key. This makes a very compact set that is very suitable for the use of linemen when making repairs and tests and wherever local batteries for operating a sounder cannot be readily obtained.

31. Army Field Telegraph Set.—In Fig. 18 is shown a main-line sounding relay and a key mounted on one base, in a

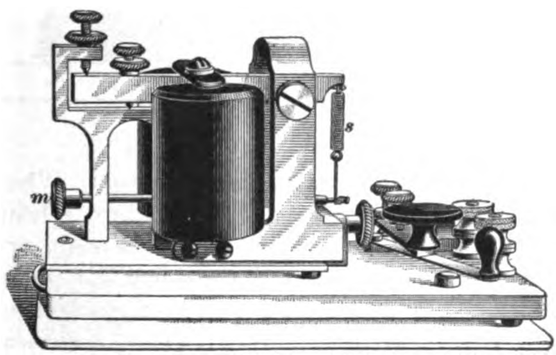


FIG. 18

very compact manner, making the set very suitable for field telegraph work. This form has been used by the United States Army Telegraph Service. The magnets are full size, and the coils may be wound to have any resistance, even as high as 300 ohms. The sounder has the wooden and aluminum resonator base that was described in connection with Fig. 10, and a nickel-plated carrying case. The outside dimensions (with the case on) are 6 inches long, $3\frac{1}{8}$ inches wide, and 4 inches deep. The tension on the retractile spring *s* is regulated by means of the thumbscrew *m*.

TELEGRAPH REGISTERS

32. Embossing Register.—An instrument that automatically records the telegraph signals by impressions made on a paper ribbon is termed a **telegraph recorder.** Its action is similar to that of a sounder. In Fig. 19 are shown

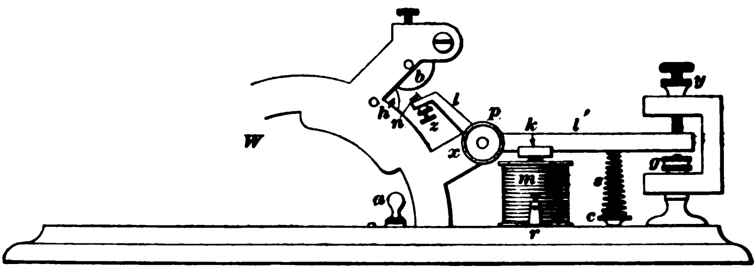


FIG. 19

the principal parts of an **embossing register.** When a current passes through the coils *m*, the armature *k* fastened to the lever *l'* is attracted. This causes a steel point, or *style*, *n* fastened to one end of the lever *l* to press against a paper ribbon that passes over a roller *b* in which a slight groove is cut. As the style *n* is adjusted over this groove, it makes a raised impression on the paper whenever the armature *k* is attracted because of the operation of the key at a distant station. The length of this impression depends on the length of time that the key is depressed, thus registering the dots and dashes.

The lever *l'* is pivoted by an arbor *p*, which may be adjusted by a screw *x*. Adjustable screws *g* and *y* limit the travel of the lever *l'* while a compression spring *s* draws the armature *k* away from the coils *m* when no current is passing through the magnet; the strength of this spring may be adjusted by a screw *c*. The style *n* may be adjusted by the screw *z*. The paper ribbon is caused to pass between the rolls *b* and *h* by clockwork *W*, which is started and stopped by a brake that is controlled at *a*. In the old-style registers this clockwork was operated by a weight. The line wire is connected to binding posts *r* on opposite sides of the magnet *m*. As

much of the apparatus as possible is protected from dust and dirt by being placed in a case of brass and glass. Even the pivots in the sides of the brass case are covered, to keep out the dust.

33. Single Embossing Register.—The embossing register is now made with single and double registering devices; a **single embossing register** is shown in Fig. 20. This

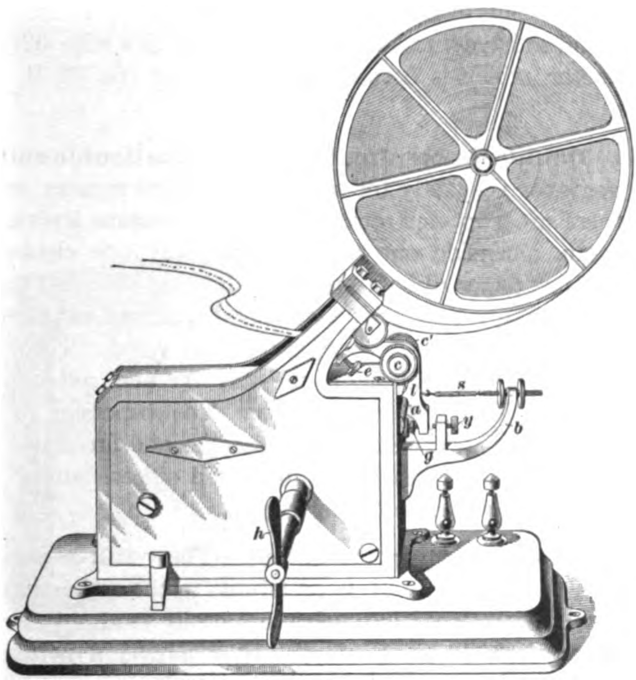


FIG. 20

register is so simple that a detailed description of it is unnecessary. The clockwork that draws the paper over the rolls is driven by a coiled spring, which is wound up by a handle *h*. By this means the paper may be constantly moving whether messages are received or not. When the armature *a* is attracted by the magnet, the bell-crank lever *l*, to which the armature is fastened, communicates its motion to the style, which in

turn embosses the characters upon the paper. The armature lever *l* is pivoted by means of the trunnion screws *c* and *c'*; its travel is limited by adjusting the front and back stop-screws *g* and *y*, respectively. The tension of the retracting spring *s*, which holds the armature lever *l* in its normal condition, is regulated by screws at the end of the projecting arm *b*. A small screw *e* regulates the position of the style.

Registers are usually connected in a local circuit and controlled by a relay in the same way as a sounder. In this case, it is wound to have a resistance of 4 ohms, with a wire .027 inch in diameter, which is between a No. 21 and No. 22 B. & S. gauge.

34. Double Embossing Register.—The **double embossing register** is exactly the same as the single register, except that there are two electromagnets, two armature levers, two styles, etc. alongside one another, but only one clockwork, one case, one paper ribbon, and reel, all being mounted on one base. It is really two independent and separate instruments, but the cost of one clock, case, and reel is saved. These registers are now provided with self-starting and self-stopping devices, which will be described later. The embossing register is used in the district-telegraph-messenger and fire-alarm systems, and somewhat in district and small offices, but is being superseded by the ink-recording register.

35. Ink-Recording Register.—The **ink-recording register**, shown in Fig. 21, is preferable to the embossing register because its record is much more easily read. It is used quite extensively in small offices and wherever a permanent record is desirable. As much of the apparatus as possible, including the clockwork, is placed inside a case made of brass and glass, and the whole is mounted substantially on a wood-and-iron-rimmed base.

When a current flowing through the magnet coils causes the armature to be attracted, the armature lever, carrying the paper with it, moves up against the disk *e*, which is kept moistened with ink by an ink roller *n*. When the current ceases, the spring *s* draws the armature lever and paper away

from the disk or printing wheel *e*, as it is called. The ink roller *n* is lightly pressed against the disk *e* by the spring *c*. The paper *p* passes through a guide on the armature lever just under the ink disk *e* and then between two rollers *a* and *r*, the rotation of which pulls the paper along. The rollers *a*, *r*, and *n*, and the disk *e* are kept rotating by the clockwork as long as signals are coming in over the line. Whenever necessary, the clock spring is wound up by the handle *H*. While

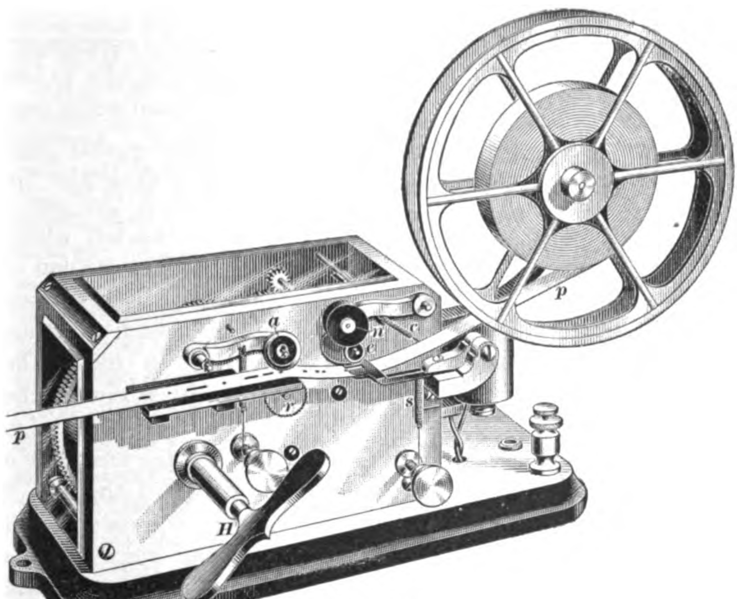


FIG. 21

receiving a message, the armature lever causes the paper to be alternately pressed against and withdrawn from the disk *e*. By this operation, a long or short mark is made on the paper, according to the duration of the contact between the disk and the paper. When used in a local circuit, the magnet coils of an ink-recording register are wound, like the embossing register, to have a resistance of about 4 ohms.

36. Self-Starting Device for Registers.—Embossing and ink-recording registers now have automatic self-starting and

self-stopping devices. In Fig. 22 are shown the escapement and the self-starting and stopping mechanism of a register controlled by the Western Electric Company. The clockwork tends to revolve the escapement wheel *e* and to make the pallet *n* and the pallet rod *g* vibrate. The pallet rod *g* and the pallet *n* are fastened to the same axle *p*. A stop-arm *m*, pivoted on the frame at *d* prevents the vibrating of the pallet rod *g* whenever it comes in line with the latter, and consequently stops the clockwork. The forward end of the arm *c* normally rests in the thread of the worm *h* that is part of the escapement wheel *e*. The rear end of this arm *c* is fastened rigidly to the piece *o*, from which projects a pin *b*. A spring *l* tends to push the piece *o* and with it the arm *c* over to the left whenever the forward end of the arm *c* is lifted out of the worm *h*, thus tending to move the stop-arm *m* out of the path of the pallet rod *g*.

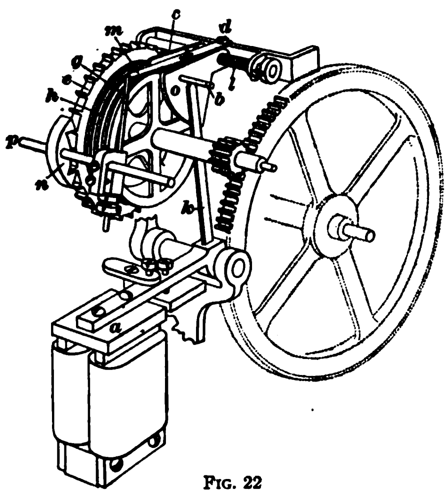


FIG. 22

When the armature *a* is attracted, the arm *k* strikes the pin *b* and lifts the piece *o*, thus raising the forward end of the arm *c* out of the worm-thread. The spring *l* immediately forces the arm *c* and the piece *o* over toward the left, thus moving the stop-arm *m* out of the path of the pallet rod *g*. The forward end of the arm *c* then drops into the extreme left-hand end of the worm *h*, leaving the pallet rod *g* and pallet *n* free to vibrate until the worm has revolved sufficiently to bring the stop-pin *m* into line with the pallet rod *g*. When a message is being received, the arm *k* continues striking the pin *b* before the stop-arm *m* can get back in the way of the pallet rod *g*. The clockwork feeds out the paper while a message is being received,

but stops when the signals have ceased long enough to allow the stop-arm m to interfere with the pallet rod g; thus, little or no paper is wasted.

37. Adjustment of Registers.—All adjustments required for a sounder are also necessary for a register, and, in addition, there is the regulation of the rollers that draw the paper along and the adjustment of the style or ink roller. The length of stroke, the distance of the armature from the cores, and the spring are adjusted exactly in the same manner as for a sounder.

After making these adjustments, the style of the embossing register should be located in the following manner: Close the local circuit and let the register run; at the same time, screw up the style until it makes a good, clear impression on the paper; then secure it in this position by tightening up the locknut. When the circuit is open, the limit screw must be so adjusted as to allow the style to just clear the paper. A paper running crooked indicates that the rollers on one side press together more tightly than on the other, and the side that carries the paper the faster should be loosened a little. Loose pivots will cause irregular dashes, sometimes too deep and again not deep enough; consequently, the pivots should be kept reasonably tight.

As in the case of a sounder, there is a fault in the local circuit when the register does not respond to the movements of the relay armature. It is very likely due to dirty relay points, a loose connection, or a weak local battery. While a register should be kept clean, it should never be taken apart out of curiosity; this remark applies to all instruments. Most of the troubles of young operators are the result of unnecessary tinkering with the instruments.

TRANSMITTING-TYPEWRITER CONNECTIONS

38. While it does not seem essential to consider the rather complicated mechanical construction and internal connections of transmitting typewriters, it is well to know how to connect them with ordinary telegraph line circuits. The depression

of a key merely makes and breaks the circuit containing the typewriter in accurately timed periods which correspond to the dots and dashes of the Morse code representing the desired character. Mr. W. H. Jones states, in the Telegraph Age, that it has been found advisable to put the typewriter in a local circuit, as shown in Fig. 23, on account of the sparking due to the inductance of the line relays and rather high line voltage, which would cause the running together of the signals, and also to eliminate the damage to the typewriters, which

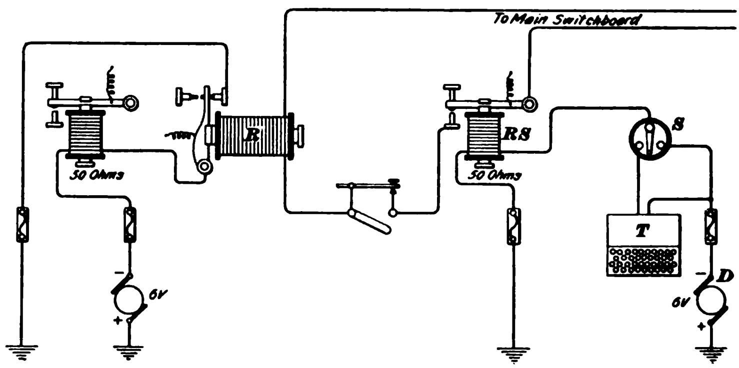


Fig. 23

are more expensive than line relays, that would be caused by high voltage due to lightning or a cross with a high-potential light or power circuit.

39. The typewriting transmitter T is placed in a local circuit with the coils of a repeating sounder R S, for which a low-wound pony relay or an ordinary Stearns quadruplex transmitter may be substituted; this circuit is supplied with current by a 6-volt dynamo D. The repeating sounder R S makes and breaks the main-line circuit, containing the main-line relay R and the key; this key should be closed and the switch S turned to the left when the typewriter T is being used. This key may be used to send messages when the typewriting transmitter is not in use, by turning the switch S to the right. Where gravity cells are used, a 5-ohm transmitter or repeating sounder may be used in place of the 50-ohm instruments and 6-volt

dynamos shown, and which are generally used in large Western Union offices. A quadruplex transmitter is about the best repeating device, but as the adjustment of a pony relay is much simpler, this relay is more suitable for the average operator in small offices. On duplex and quadruplex circuits, it is merely necessary to insert a thin, flat, double-contact wedge, in which the flexible conductors running to the transmitting typewriter terminate, in the regular transmitting Morse key where the circuit-closer lever is placed when closed.

TELEGRAPH ELECTROMAGNETS

GENERAL DESCRIPTION

40. In Fig. 24 are shown the relative sizes of the various parts of a type of electromagnet largely used in the most suc-

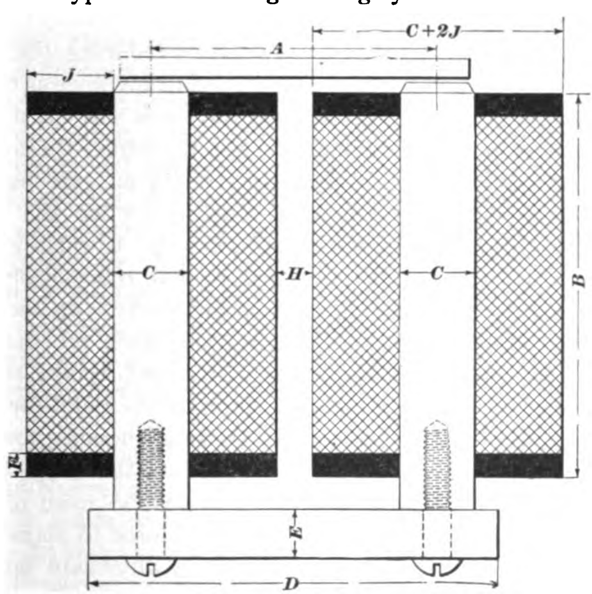


FIG. 24

cessful American telegraph instruments. It consists of the cores *C*, which are cylindrical in form and around which the coils of insulated copper wire are wound; a rectangular yoke

piece E, which unites the two cores, and the rectangular armature A, which is movable and forms a very important part of the magnetic circuit. The magnetism shows its presence by attracting this armature.

MAGNETIC CIRCUIT OF TELEGRAPH INSTRUMENTS

41. With a given number of ampere-turns, the strength of an electromagnet can be increased by decreasing the magnetic reluctance of the magnetic circuit. This reluctance can be decreased by decreasing the length of the magnetic circuit, by increasing the cross-section of both the iron and the air gap, and by using iron having a higher permeability. It is better to make the path of the lines of force short rather than to increase the cross-section of the iron, because the shorter a magnet of given strength, the quicker it will magnetize and demagnetize, and this is very desirable indeed in electromagnets for telegraph instruments. To aid in reducing the reluctance, the cores and the yoke piece should fit together as tightly as possible, and the air gap between the cores and the moving armature should be as short as the use for which the magnet is designed will allow. The reluctance of the air gaps between the two cores and the armature, especially when the armature is at its greatest distance from the cores, is much greater than that of all the rest of the circuit, so that in telegraph magnets the length of the cores will have little effect on the total reluctance of the circuit. The cores, therefore, are made as short and as small in diameter as practicable, almost regardless of the effect on the reluctance, in order to make the magnet quick-acting. The cores must be long enough, however, to hold the necessary number of turns; and the cross-section of the cores must be great enough to allow the given number of ampere-turns to set up enough lines of force to attract the armature, and without bringing the iron anywhere near its magnetic saturation point.

42. Residual Magnetism.—When a mass of soft iron in a coil of wire is magnetized by passing a current through the coil, an appreciable time elapses after the circuit is first

closed before the iron reaches the maximum state of magnetization that the current in the surrounding coil is capable of producing. And, when the current is stopped, the iron does not lose its magnetism instantly. Furthermore, the iron will retain some of its magnetism for an indefinite length of time, depending on the magnetic quality of the iron. This is termed **remanent,** or, more properly, **residual, magnetism,** and is a result of magnetic hysteresis. The larger the magnetic hysteresis in iron, the more persistently does it hold on to its residual magnetism.

An iron that has a large hysteresis factor may retain but very little magnetism, but it may hold on to whatever amount it does have with a great deal of force, and may require severe treatment for its removal. The tenacity with which an iron holds on to its residual magnetism is called its **coercive force,** which may also be defined as the amount of negative, or opposing, magnetizing force that is required to reduce the residual magnetism to zero. On the other hand, soft irons, in which the hysteresis is very small, may, if properly handled, be made to retain considerable magnetism, but the slightest jar or touch will remove it entirely, so that not even the least trace is left. The coercive force of these irons is very small. To secure quickness of action and freedom from residual magnetism, the very best quality of soft iron, that is, with the highest permeability and lowest coercive force, should be used. Under ordinary usage in a telegraph instrument, very good soft iron loses all its magnetism almost instantly when the magnetizing force is removed.

43. There are some brands of cold-blast charcoal iron, such as Norwegian, Swedish, and a Lowmoor iron, that, when carefully annealed, show scarcely a trace of residual magnetism, and these brands are therefore preferred in the manufacture of magnet cores. After annealing, it is very important that the iron be left black and that no attempt be made to brighten it up. If it is filed, or touched ever so lightly with a tool of any kind, it will be slightly hardened, and will certainly show traces of residual magnetism. For the same

reason, the armature of an electromagnet should never be permitted to hammer on its cores.

A magnet with cores and yoke made of the best magnetically soft-iron wire of small size would be an efficient one, and, even with the cores only made of iron wire, it should be more efficient than one with solid cores, if the joints between the cores and yokes were properly made. It is rather difficult, however, to do this.

44. Time-Constant.—When current is first turned into a circuit possessing considerable self-induction, it is resisted rather by the inductance than by the resistance of the circuit. The rate of increase in the strength of the current depends on the ratio of the inductance to the resistance; that is, upon the ratio $\frac{L}{R}$. This ratio represents the time that it takes for the current to reach .63, or nearly $\frac{2}{3}$, of its final strength. Thus, if in any circuit the inductance, in henrys, is divided by the resistance, in ohms, the ratio gives the **time-constant** of the circuit, or it expresses the time that it will take for the current to reach about two-thirds of its final value. Anything that will increase the resistance R without increasing the inductance L will diminish the ratio $\frac{L}{R}$, and, hence, render the conditions more favorable for rapid working.

45. For example, rewinding a magnet with more turns of a finer wire will increase the resistance, but to keep the ampere-turns the same, the current required must of course be less. If the magnet were rewound to have twice the number of turns with a wire of one-half the cross-section, the ratio $\frac{L}{R}$ would not be affected. For the inductance L is proportional to the square of the number of turns, and, hence, it is four times as great as before, and, there being twice as many turns of a wire of one-half the cross-section, the resistance R is also four times as great as before. Consequently, the ratio $\frac{L}{R}$ has the same value

as before. In order, however, to get twice as many turns of wire in exactly the same space it will be necessary to use a wire of somewhat less than one-half the cross-section, because the smaller the wire, the larger is the percentage of space that is occupied by the insulating covering of the wire; hence, the resistance will increase faster than the square of the number of turns, and, consequently, the ratio $\frac{L}{R}$ will diminish. With a No. 24 B. & S. double silk-covered wire, the copper occupies 62 per cent., but with a No. 26 B. & S. wire the copper occupies only 55 per cent. of the volume of the coil, or a loss of 7 per cent., on account of the larger proportion that the thickness of the insulating covering now bears to the diameter of the bare wire.

Although not stated, it has been assumed in the foregoing that the circuit possesses no electrostatic capacity, or, at least, a perfectly negligible amount of it. If it also possesses electrostatic capacity in addition to resistance and inductance, it becomes a more complicated matter, and it will not be advisable to take it up here.

46. That some idea may be formed of the value of such quantities, the inductance and time constant of a few instruments are given. A Morse 148-ohm relay, as ordinarily adjusted, has an inductance L of about 5 henrys; therefore, the time constant is $5 \div 148 = .034$ second. When the armature touches the core, however, the inductance is 8 henrys and the time constant is .054 second. A polarized 417-ohm relay, with the armature .004 inch from the cores and a current of 6.3 milliamperes, the inductance L is 1.72 henrys and the time constant is $1.72 \div 417 = .004$ second. A 20-ohm sounder, with the armature .004 inch from the cores and a current of 125 milliamperes, the inductance is 191 millihenrys and the time constant is .0095 second. A 14-ohm sounder has an inductance of 265 millihenrys and a time constant of .019 second. With a current of .05 ampere and with the armatures .014 inch from the cores in each case, the inductance of the standard 150-ohm relay of the Postal Telegraph-Cable Company is 2.6

henrys; the inductance of the 75-ohm relay is .81 henry; and the inductance of the 37.5-ohm relay is .55 henry.

47. The less iron used in an electromagnet, the shorter the cores; and the less complete the iron circuit is made, the quicker the magnet acts. Some relays used in repeater and quadruplex sets have exceptionally short cores, which make them act very promptly, in fact, a polarized relay used by the Western Union Telegraph Company in some of its quadruplex sets has no yoke piece. The absence of the yoke piece doubtless makes the magnet less efficient, requiring on it more ampere-turns to give the same pull on the armature; but in this case it is more important to have a quick-acting relay than one of the highest efficiency.

The speed of a solid-core magnet may be increased by slotting the core parallel to its axis to about one-quarter of its diameter, and by drilling a hole along the axis nearly the entire length of the core, starting from the pole face next to the armature. The solid cores act as though they required time for the magnetism to soak in. For the most rapid operation the magnetic circuit should be laminated and the laminations insulated with varnish, oxide, or tissue paper.

48. Proper Proportions of a Telegraph Magnet.—The best theoretical proportions to secure the maximum magnetic effect from a given number of ampere-turns have been found to be as follows: Make the yoke, cores, and armature of equal length, the yoke being of somewhat greater cross-section than the cores, and the armature of equal cross-section, but broader and thinner than the yoke. However, in order to make a quick-acting magnet, a very important consideration in telegraph apparatus, these theoretical proportions may sometimes be modified with practical advantage.

The most important quality essential to an electromagnet for telegraph apparatus is the quickness with which it responds when the circuit is closed or opened, and then comes its efficiency, that is, its maximum attractive force with a given number of ampere-turns. As these two properties oppose each other, it is necessary to sacrifice, to a certain extent, the

efficiency in order to obtain quickness. Investigations have shown that the outer diameter of the coils should be three times the diameter of the cores, and that the length of each coil should be equal to its own diameter, although, as a matter of fact, the coils are usually a little longer than their diameters. Fig. 24 shows the relative size of the magnet of a Western Union relay. Telegraph companies generally consider that the best results are obtained by making the area of the poles of the magnet practically the same size as the cores, that is neither enlarging nor reducing the area of the pole faces, and the pole faces should be perfectly plane. It is best (before annealing, however) to file off the sharp edge, thus reducing the pole area a trifle, but this also reduces the magnetic leakage, and the one counterbalances the other.

49. Covering for Coils.—The coils in all telegraph instruments are usually covered with a polished vulcanized-rubber casing to protect them from dust and mechanical injury and to add to their appearance. In all electromagnets used in telegraph instruments, the iron armature should be so adjusted, that it can never come so near the iron cores or pole pieces that one thickness of ordinary writing paper cannot be drawn between them. This is to prevent the armature from sticking to the cores and also to keep the armature from striking the cores. The continual striking of an armature against the cores is sufficient to harden them and cause them to retain their residual magnetism more tenaciously.

WINDING FOR SOUNDERS AND RELAYS

50. The resistance of a line increases directly as its length. With a given line circuit, the only way to increase the current is to increase the difference of potential at the terminals of the circuit. But as it is neither advisable nor practicable in telegraph circuits to use a very high electromotive force, it is usually impossible to get a current through a long and, therefore, high-resistance line that is strong enough to operate an ordinary sounder properly. Neither is it possible to decrease

the resistance, for to decrease the resistance of a line sufficiently would require such a large wire that its cost would prohibit its use entirely. But, by putting the sounder, with a separate battery, in a local circuit that is opened and closed by the armature of a relay, the desired results can be obtained, because only sufficient pull need be exerted on the relay armature to bring two contact points together; also, with the sounder in a local circuit of low resistance, there is no difficulty whatever in securing a current large enough, even with only a few cells of battery. By having sufficient turns of wire on the relay, a very small current will be sufficient to cause the magnet to attract the armature and so close the local circuit containing the sounder and local battery.

51. Coils Designated by Their Resistance.—The resistance of a wire varies directly as its length. Therefore, the number of turns in a coil, as this varies as the length of the wire, has a definite relation to the resistance of the coil, so that the resistance of a coil may be taken as a measure of the number of turns of wire it contains. Now, it is easy to measure the resistance of a finished coil, but it is not an easy matter to determine the number of turns or the length of wire used. On account, therefore, of this practical convenience, and not because the resistance itself is a desirable quantity, it is customary to speak of an electromagnet as having a certain resistance instead of a certain number of turns, and, therefore, to designate it by its resistance. Thus, we speak of a 150-ohm relay and not of a relay of 8,640 turns, although this latter would be a more direct way of indicating the value of the relay, because the more turns there are, the smaller need be the magnetizing current for a given magnetization.

52. Ampere-Turns for Relays and Sounders.—Why the winding of a relay for a long-line circuit should be different from the winding of a sounder for a short or local circuit will now be explained. The same principle will explain the reason for winding relays, some with low-resistance coils of relatively few turns for short lines, and others with high-resistance coils of a relatively large number of turns for long lines.

With a magnetic core of given length and cross-section, the force with which the armature is drawn toward the cores is approximately proportional to the square of the product of the current and the number of turns in the coil; this product is called the **ampere-turns.** There are two limiting conditions, however: one is that the depth of winding for short-core electromagnets, such as are used in telegraph instruments, shall not exceed the diameter of the core, making the outside diameter over the coil about three times that of the core; the other is that the cores shall never even approach magnetic saturation. In regard to the latter point, it is sufficient to state that, in telegraph magnets, the dimensions of the iron parts, the number of turns of wire in the coils, and the strength of current are such that magnetic saturation is never closely approached.

53. It has been determined that a sounder wound with about 940 turns of wire works well when a current of $\frac{1}{4}$ ampere is flowing through the coils. This gives $.25 \times 940 = 235$ ampere-turns as the most favorable condition for its operation. In order to keep this product constant, the number of turns should vary inversely as the current strength. That is, with a given battery, the larger the resistance of the circuit, and, therefore, the smaller the current, the larger should be the number of turns in the coils of the electromagnet. But the winding space is limited, and it is not practical to use a wire smaller than No. 40 B. & S. gauge, so that there is a limit to the number of turns that can be wound on the iron core. Consequently, if the product of the maximum number of turns that can be put in the given space, by using the smallest wire, and the largest current obtainable over a line circuit with an electromotive force as high as it is practical to use is less than 235, the sounder cannot be successfully used on that line circuit. For lines over 20 miles in length, it is more economical and successful to use a relay and a lower electromotive force, with the sounder in a local circuit, than to attempt to get a current large enough to work the sounder in the main line by using the high electromotive force that would be required. A relay that is not

designed to give a loud sound, and requiring much less energy to operate its small, light armature, can be used to better advantage to control the opening and closing of a local circuit containing a sounder and a separate battery.

54. If a sounder of 4 ohms resistance is put in a local circuit with two gravity cells, the current may be calculated as follows: As the resistance of one sounder is 4 ohms, and the internal resistance of two cells is 4 ohms, hence, the total resistance is 8 ohms. As the resistance of the connecting wires is very small, it may be neglected. The electromotive force of two gravity cells is about 2 volts. Therefore, the current will be $2 \div 8 = \frac{1}{4}$ ampere. As $\frac{1}{4} \times 940 = 235$ ampere-turns, this is the most favorable condition for the successful working of a sounder, as already mentioned.

For example, take a line of No. 14 B. & S. gauge copper wire 10 miles in length, with five stations on it. The line resistance will be about 80 ohms, the resistance of five 4-ohm sounders is 20 ohms, and the internal resistance of 30 cells is 60 ohms; therefore, the total resistance is 160 ohms, and the current is $30 \div 160 = .1875$ ampere. As the ampere-turn is $.1875 \times 940 = 176$, the number of ampere-turns is too small to operate the sounder satisfactorily. By using 50 cells, the current will be equal to $\frac{50}{80+20+100} = .25$ ampere. So that the 10-mile circuit will require 50 cells, if 4-ohm sounders are used, in order to operate them under the most favorable conditions.

55. To reduce the number of cells required, relays may be used with the sounders in local circuits. A 150-ohm relay has 8,640 turns of wire in the coils, and requires .02 ampere to work it, though this makes no allowance for line leakage. Hence, the minimum ampere-turns required to work an ordinary relay are $8{,}640 \times .02 = 173$. As the line under consideration is a short one, a 37.5-ohm relay will be tried. The line resistance is 80 ohms, the resistance of five 37.5-ohm relays is 187.5 ohms, and the internal resistance of 12 cells is 24 ohms; therefore, the total resistance is 291.5 ohms, and

the current is $12 \div 291.5 = .041$ ampere. The 37.5-ohm relay, which is made by connecting the two coils of a 150-ohm relay in parallel instead of in series, has one-half of .041 ampere in each coil, giving $8,640 \times \frac{.041}{2} = 177$ ampere-turns. This relay will then work all right, because 177 is greater than 173.

The system is now working with 12 cells of battery in place of 50 when 4-ohm sounders were tried. Two cells in each local circuit will only bring the total number of cells up to 22. Thus, 28 cells are saved, and, even if the main-line current does vary somewhat, the sounders will work more uniformly, which would not be the case if the sounders were in the main-line circuit. When the signals are read by sound, it is essential that the sounders work the same at all times.

EXAMPLE.—A current of 20 milliamperes is passing through a relay with its coils connected in series and having a resistance of 400 ohms, giving, say, 10 turns per ohm. A similar relay has its two coils connected in parallel and the same current flows through the relay. What are the relative magnetic strengths of the two relays?

SOLUTION.—Ten turns per ohm gives $400 \times 10 = 4,000$ turns. The ampere-turns for the first relay is $.02 \times 4,000 = 80$. As the two coils of the second relay are in parallel the current will divide, .01 ampere flowing through each coil which has $200 \times 10 = 2,000$ turns. Then each coil has $2,000 \times .01 = 20$ ampere-turns and both coils will have $2 \times 20 = 40$ ampere-turns. Hence, the magnetic pull of the first relay is twice that of the second. However, it must be remembered that the first relay requires twice the voltage to force the same current through it. Ans.

56. Resistance of Magnets in Same Circuit.—All telegraph electromagnets, such as relays, main-line sounders, etc., that are connected in series in the same line circuit, should have the same resistances. This will cause all the electromagnets so connected to work equally well.

57. Winding for Reduction of Sparking.—It has long been recognized that the sparking at the contacts of a local telegraph circuit can be reduced by winding the magnet with two wires connected in parallel with each other. That is, if, instead of being wound with one wire of the proper cross-section, the coil of a magnet is wound with two wires of half

that cross-section and the same number of turns, these two windings being connected in parallel and giving the same magnetizing effect with a given current as does the single winding, the sparking will be less.

In 1899, it was discovered, and the method patented, that a magnet wound with two wires lying side by side throughout their length and connected in series gives less sparking than the same magnet wound in the ordinary way with the same size wire and the same number of turns. In fact, it is even claimed that the spark at the points of rupture may be almost wholly eliminated, thus protecting the contacts against destructive sparking. A coil wound in this manner is shown in Fig. 25. The reduced sparking is due to a condenser action between adjacent turns, which, in this method of winding, have considerably more difference of potential between them than would be the case in the ordinary method of winding. This

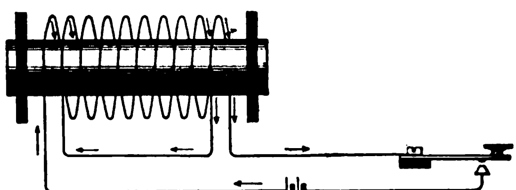


FIG. 25

creates electrostatic charges that balance to a certain extent the self-induction. As there is, in this method, a greater potential difference between adjacent turns, better insulation might be required on the wire in some cases, and, furthermore, it is more difficult to wind the wire in this manner.

Another method by which sparking may be avoided, or at least much reduced, consists in permanently joining together the two contact pieces by a non-inductive resistance so large that the current passing through it, when the contact is broken, is small enough not to be injurious or very wasteful. The same object is accomplished by connecting a condenser across the contact points.

58. Varley Coils.—The Varley Duplex Magnet Company winds its coils with bare wire. In order to prevent the

short-circuiting between the various convolutions, a silk thread is wound parallel with the bare wire throughout its length, so that the adjacent convolutions are always held a slight distance apart. Between the several layers of the winding are introduced thin layers of oiled paper. This winding is accomplished entirely by automatic machinery and the coils produced are very perfect. The machines are run at a high speed, and, at the proper intervals, the layers of paper are introduced without stopping the machinery or without the volition of the operator. This method, besides being cheaper than the method in which the insulated wire is used, has the

TABLE I

DIMENSIONS OF ELECTROMAGNETS

Instrument	Part of Electromagnet								
	A Inches	*B* Inches	*C* Inch	*D* Inches	*E* Inch	*F* Inch	*H* Inch	*J* Inch	*C* + 2 *J* Inches
1	1.3750	2.0000	.3750	2.1250	.2500	.1250	.1875	.4375	1.2500
2	1.6250	1.5000	.4687	2.1250	.2187	.1250	.7175	.2187	.9062
3	1.7500	1.4375	.5000	2.3750	.2500	.1562	.1250	.5937	1.6875
4	1.0937	1.0625	.3750	1.6250	.1875	.1250	.1875	.2812	.9375
5	1.8125	3.3225	.6250	2.7500	.2500	.1875	.4375	.3750	1.3750
6	1.3750	2.1250	.4375	2.1250	.2500	.1250	.1875	.4375	1.1250

additional advantage of making possible a given number of turns of a certain size of wire in a smaller space than can be obtained by the old method. Again, the convolutions are arranged with practically perfect uniformity, in decidedly sharp contrast to the results produced by the usual method, in which the wire is fed to the machine by hand.

59. Dimensions of Telegraph Instruments.—Table I, in connection with Fig. 21, which shows the form of electromagnets employed in telegraph and signal work, will be a useful guide in designing others for a similar purpose, for they are the result of considerable experimenting and practical experience.

No. 1 gives the dimensions of a Western Union relay; when this relay is wound with No. 30 B. & S. gauge silk-covered copper wire, it will have a resistance of 150 ohms at 60° F. No. 2 is a Western Union sounder; its resistance will be 1.9 ohms when wound with No. 22 B. & S. gauge silk-covered copper wire. No. 3 is the electromagnet used in a stock printer, and has a resistance of .7 ohm when wound with No. 17 B. & S. gauge double cotton-covered wire; it is very quick-acting. No. 4 is an ordinary bell magnet, having a resistance of about 25 ohms when wound with No. 30 B. & S. gauge single cotton-covered copper wire. No. 5 is a magnet used for operating semaphores in railroad signaling systems; it has a resistance of 1.2 ohms when wound with No. 17 B. & S. gauge single cotton-covered copper wire; it is slow-working, but for the use to which it is put this is no objection. No. 6 is a 150-ohm relay specified by some telegraph companies; it differs from No. 1 only in the dimensions B and C. The specifications for No. 6 further state that the core shall be $2\frac{1}{4}$ inches long, length of armature lever $2\frac{1}{3}$ inches, conductivity of copper wire at least 97 per cent. that of pure copper, and an iron rim around the edge of an oiled wooden base.

60. Coils on Standard Instruments.—Standard telegraph 4-ohm sounders are wound with 10 layers, of 47 turns each, or a total of 940 turns, of No. 24 B. & S. silk-covered wire. Some 4-ohm sounders are wound with 615 turns of No. 22, B. & S., single silk-covered wire on each spool, the mean diameter of the coil being .69 inch. Some 20-ohm sounders have 1,876 turns, are wound in 14 layers, of 67 turns each, of No. 25 B. & S. wire. The Western Union 150-ohm relay has 4,250 turns of No. 29 B. & S. single silk-covered wire on each spool. The Postal Telegraph-Cable relay wound to 37.5 ohms has 728 feet of No. 27 B. & S. wire; wound to 75 ohms, it has 1,092 feet of wire having a sectional area of 150.7 circular mils; wound to 150 -ohms, it has 1,456 feet of No. 30 B. & S. wire, giving 8,640 turns in 30 layers of 144 turns each; wound to 300 ohms, it has 2,184 feet of wire, having a sectional area of 75.3 circular mils; wound to 450 ohms, it has 2,730

feet of No. 32 B. & S. wire; wound to 600 ohms, it has 2,912 feet of No. 33 B. & S. wire. Four-ohm ink and embossing registers are wound with about No. 22 B. W. G. wire. Main-line sounders and registers, for use on line circuits not over 20 miles long, are often wound with No. 30 B. & S. wire.

CURRENT STRENGTHS REQUIRED BY TELEGRAPH INSTRUMENTS

61. The following are the current strengths best adapted and used in practice for the telegraph instruments named:

INSTRUMENT	AMPERE
4-ohm sounder	.25
20-ohm sounder (depending on the size)	.098 to .18
40-ohm main-line sounder	.04 to .07
200-ohm sounder	.026
30-ohm pony relay about	.1
150-ohm relay	.018 to .02
300-ohm relay	.01 to .015
Postal Telegraph quadruplex relay	.02
200-ohm Wheatstone relay (used with a condenser)	.008 to .012

In the case of instruments connected in a line wire from which there is more or less leakage, the figures given here represent effective currents. By *effective current* is meant the difference between the maximum current, which flows when all the keys are closed, and the minimum current, which flows when a distant key is opened. For instance, in line circuits a 150-ohm relay usually requires .03 to .04 ampere. Postal Telegraph-Cable Company's relays wound to 37.5 ohms require .05 to .06 ampere; wound to 75 ohms, .04 ampere; wound to 300 ohms, .022 ampere; wound to 600 ohms, .014 ampere. A 20-ohm sounder, operated by 40 volts in series with 200 ohms, requires about .2 ampere.

TABLE II
COTTON-COVERED. ANNEALED COPPER WIRE

Size of Wire B. & S. Gauge	Resistance of 1.000 Feet at 68° F. or 20° C. Ohms	Bare Wire		Single Cotton-Covered			Double Cotton-Covered			Triple Cotton-Covered		
		Diameter d Mils	Area d^2 Circular Mils	Diameter Over Insulation d_x Mils	Number of Wires per Inch $\frac{1,000}{d_x}$	Number of Wires per Square Inch $\left(\frac{1,000}{d_x}\right)^2$	Diamter Over Insulation d_x Mils	Number of Wires per Inch $\frac{1,000}{d_x}$	Number of Wires per Square Inch $\left(\frac{1,000}{d_x}\right)^2$	Diameter Over Insulation d_x Mils	Number of Wires per Inch $\frac{1,000}{d_x}$	Number of Wires per Square Inch $\left(\frac{1,000}{d_x}\right)^2$
0000	.04901	460.	212,000							478	2.09	4.36
000	.06180	410.	168,000							428	2.33	5.42
00	.07793	365.	133,000							383	2.61	6.81
0	.09827	325.	106,000				339	2.94	8.64	343	2.91	8.46
1	.1239	289.	83,700				303	3.30	10.8	307	3.25	10.5
2	.1563	258.	66,400				272	3.67	13.4	276	3.62	13.1
3	.1970	229.	52,600				242	4.13	17.0	247	4.04	16.3
4	.2485	204.	41,700	211	4.73	22.3	216	4.62	21.3	220	4.54	20.6
5	.3133	182.	33,100	189	5.29	27.9	194	5.15	26.5	198	5.05	25.5
6	.3951	162.	26,300	169	5.91	34.9	174	5.74	32.9	178	5.61	31.4
7	.4982	144.	20,800	151	6.62	43.8	156	6.41	41.0	160	6.25	39.0
8	.6282	128.	16,500	136	7.35	54.0	141	7.09	50.2	145	6.89	47.4
9	.7921	114.	13,100	121	8.26	68.2	126	7.93	62.8	130	7.69	59.1
10	.9989	102.	10,400	108	9.25	85.5	112	8.92	79.5	116	8.02	64.3
11	1.260	90.7	8,230	97	10.3	106.	101	9.90	98.0	105	9.52	90.6
12	1.588	80.8	6,530	87	11.4	129.	91	10.9	118.	95	10.5	110.
13	2.003	71.9	5,180	78	12.8	163.	82	12.1	146.	86	11.6	134.
14	2.525	64.1	4,110	70	14.2	201.	74	13.5	182.	78	12.8	163.
15	3.184	57.1	3,260	63	15.8	249.	67	14.9	222.	71	14.0	196.
16	4.015	50.8	2,580	56	17.8	316.	59	16.9	285.	63	15.8	249.
17	5.064	45.3	2,050	50	20.0	400.	53	18.8	353.	57	17.5	306.
18	6.385	40.3	1,620	45	22.2	492.	48	20.8	432.	52	19.2	368.
19	8.051	35.9	1,290	39	25.6	655.	43	23.2	538.	47	21.2	449.

TABLE III

SILK- AND COTTON-COVERED, ANNEALED COPPER WIRE

Size of Wire B. & S. Gauge	Diameter Over Insulation, in Mils				Turns per Linear Inch				Turns per Square Inch			
	Single Cotton	Double Cotton	Single Silk	Double Silk	Single Cotton	Double Cotton	Single Silk	Double Silk	Single Cotton	Double Cotton	Single Silk	Double Silk
20	37.861	42.161	34.261	36.161	25.7	22.5	27.70	26.22	660.5	506.3	767.3	687.5
21	34.362	38.662	30.762	32.662	28.3	24.5	30.97	29.07	800.9	600.2	959.1	845.0
22	31.247	35.547	27.647	29.547	31.0	26.7	34.39	32.11	961.0	712.9	1,182.7	1,031.0
23	28.471	32.771	24.871	26.771	34.4	28.97	38.19	35.53	1,183.0	839.2	1,458.5	1,262.4
24	26.000	30.300	22.401	24.300	36.9	31.35	42.37	39.14	1,321.6	982.8	1,795.2	1,532.0
25	23.800	28.100	20.200	22.100	38.0	33.92	47.02	42.94	1,444.0	1,150.8	2,210.9	1,843.8
26	21.840	26.140	18.240	20.140	42.0	36.29	52.06	46.81	1,764.0	1,317.0	2,710.3	2,191.2
27	20.095	24.395	16.495	18.395	48.0	38.95	57.67	51.59	2,304.0	1,517.2	3,326.0	2,661.6
28	18.541	22.841	14.941	16.841	53.0	41.61	63.36	56.43	2,809.0	1,731.0	4,014.5	3,184.5
29	17.157	21.457	13.557	15.457	56.5	44.27	70.11	61.56	3,192.3	1,959.9	4,915.5	3,789.8
30	15.925	20.225	12.325	14.225	59.66	46.93	77.14	66.79	3,559.2	2,202.5	5,950.2	4,461.0
31	14.828	19.128	11.228	13.128	64.12	49.78	84.64	72.39	4,112.2	2,478.0	7,164.0	5,240.0
32	13.850	18.150	10.250	12.150	68.60	52.34	92.72	78.19	4,692.5	2,739.5	8,597.5	6,114.0
33	12.980	17.280	9.380	11.280	73.05	55.10	101.65	84.17	5,333.5	3,036.1	10,332.	7,085.0
34	12.204	16.504	8.504	10.504	77.90	57.57	112.11	90.44	6,068.5	3,314.2	12,570.	8,179.5
35	11.514	15.841	7.914	9.814	82.60	60.04	119.70	96.90	6,773.3	3,605.0	14,328.	9,389.5
36	10.900	15.200	7.300	9.200	87.10	62.51	130.15	103.55	7,586.5	3,907.5	16,940.	10,722.
37	10.353	14.653	6.753	8.653	91.87	64.70	140.60	110.20	8,440.0	4,186.1	19,770.	12,145.
38	9.865	14.165	6.265	8.165	95.0	66.80	151.05	116.85	9,025.0	4,462.2	22,820.	13,655.
39	9.431	13.731	5.831	7.731	100.7	68.80	163.04	122.55	10,140.5	4,733.6	26,700.	15,018.
40	9.044	13.344	5.344	7.344	106.0	71.20	177.65	129.20	11,236.0	5,069.8	31,559.	16,692.

COIL-WINDING TABLES

62. The following tables are useful for magnet-winding calculations. In Table II are given the diameters of cotton-covered, annealed, copper wire in sizes up to No. 19 B. & S.; these sizes are seldom, if ever, insulated with silk. In Table III are given the diameters and turns of wire between Nos. 20

TABLE IV

ANNEALED COPPER WIRE

Size of Wire B. & S. Gauge	Diameter of Bare Wire Mils d	Area of Bare Wire Circular Mils d^2	Resistance of 1,000 Feet of Bare Wire at 68° F. Ohms 20° C.	Resistance of Insulated Wire in Ohms per Cubic Inch		
				Single Cotton	Double Cotton	Single Silk
20	31.961	1,021.	10.15	.646	.533	.801
21	28.462	810.1	12.80	.981	.795	1.261
22	25.347	642.7	16.14	1.502	1.188	1.956
23	22.571	509.5	20.36	2.359	1.772	3.049
24	20.100	404.0	25.67	3.582	2.595	4.739
25	17.900	320.4	32.37	5.831	3.802	7.489
26	15.940	254.0	40.82	6.941	5.552	9.031
27	14.195	201.5	51.46	10.814	8.078	13.92
28	12.641	159.8	64.90	17.617	11.54	26.86
29	11.257	126.7	81.84	25.50	16.47	41.29
30	10.025	100.5	103.2	34.80	23.43	62.98
31	8.928	79.71	130.1	48.50	32.83	95.70
32	7.950	63.20	164.1	73.80	46.19	144.70
33	7.080	50.13	208.9	104.5	64.30	217.8
34	6.304	39.74	260.9	151.4	70.38	342.1
35	5.614	31.52	329.0	202.0	125.9	489.0
36	5.000	25.00	414.8	298.8	166.3	721.1
37	4.453	19.83	523.1	418.0	225.6	1,062.
38	3.905	15.72	659.6	567.0	305.5	1,557.
39	3.531	12.47	831.8	811.0	409.8	2,266.
40	3.144	9.89	1,049.	1,113.	545.5	3,400.

and 40 B. & S. G.; these sizes are seldom insulated with more than two layers of cotton or silk. In Table IV are given the diameters and areas of bare wires and the resistances of bare and insulated wires between Nos. 20 and 40 B. & S.

There is considerable variation in the thickness of insulation applied to wires. However, the data given here is based on samples of actual winding and has been found in calculations to give as close an approximation as is afforded by any of the formulas on the subject.

By the term **ohms per cubic inch** is meant the resistance, in ohms, of all of a given size of insulated wire that can be put in a space of 1 cubic inch.

TABLE V

DOUBLE SILK-COVERED COPPER WIRE

Size of Wire B. & S. Gauge	Ohms per Cubic Inch o	u	Weight per Cubic Inch Pounds
20	.76	.79	.24
22	2	.69	.23
24	5	.62	.21
26	12	.55	.19
28	25	.49	.17
30	54	.43	.14
32	105	.37	.12
34	195	.31	.08
36	355	.25	.075
38	630	.19	.06
40	1,050	.13	.05

Turns per square inch mean the number of turns of which the ends would be exposed in 1 square inch if the wound coil were cut in a plane passing through the axis of the core.

63. Table V, taken from the "Physical Laboratory Notes" of the Massachusetts Institute of Technology, gives the ohms (o) per cubic inch for some sizes of double silk-covered copper wire. It is not calculated from any formula, but is based on data obtained in winding a few actual coils. The column headed u gives the ratio of the volume of the copper to the total volume of the coils as actually wound, and the last column enables one to determine the weight of wire necessary

for a coil when the volume is known. As the wire becomes smaller, the insulation on it occupies a larger proportion of the total volume. For instance, a spool filled with No. 40 has only 13 per cent. of its volume occupied with copper.

64. Enamel-Covered Wire.—Coils are now wound with wire having a very thin coating of hard-baked enamel. This insulation may be very much thinner than silk or cotton and yet have fully as high insulating properties, nor does it crack off if handled with reasonable care. A coil wound with such wire has the advantage of being non-inflammable, will stand a much higher temperature than one insulated with cotton or silk and more turns, or the same number of turns of a larger wire, can be put in the same space. Sometimes the whole coil, after being wound, is dipped in enamel and again baked. Whenever the wire is smaller than No. 23 B. & S., the coils of telegraph instruments can be advantageously wound with enamel-covered instead of silk-covered wire.

MAGNET-WINDING CALCULATIONS

65. Determining Length of Wire in Coil.—When the spool shown in Fig. 26 is filled with wire, the inside diameter d_1 may be considered to be the same as the outside diameter of the iron core for the insulation between the iron core and the wire is small enough to neglected.

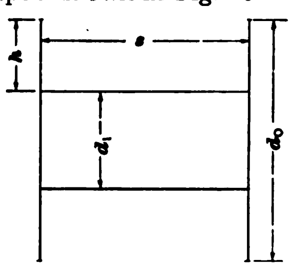


FIG. 26

Suppose that a winding space has a length s, and a depth $h = \frac{d_0 - d_1}{2}$ and that the wire is to be wound, in layers, as closely as possible. If the diameter of the bare wire is d and the diameter over the insulation is d_x, the space will hold $\frac{s}{d_x}$ turns in each layer, there will be $\frac{h}{d_x}$ layers, and the total number of turns in the coil will be

$$N = \frac{s\,h}{d_x^2}, \qquad (1)$$

in which N = number of turns on coil;
s = length of coil;
h = depth of space to be filled;
d_x = diameter of wire over insulation.

If the value $\frac{d_0-d_1}{2}$ is substituted for h the formula becomes

$$N=\frac{s\,(d_0-d_1)}{2\,d_x^2}, \qquad (2)$$

in which d_0 = total diameter of coil;
d_1 = inside diameter of coil or diameter of core.

The mean diameter of all the turns of wire is d_0-h; or substituting for h its value $\frac{d_0-d_1}{2}$ the mean diameter is $d_0-\frac{d_0-d_1}{2}$ $=\frac{d_0+d_1}{2}$ As the length l of a mean turn is $\frac{\pi\,(d_0+d_1)}{2}$, the total length L of the wire is

$$L=\frac{\pi\,N\,(d_0+d_1)}{2}, \qquad (3)$$

or substituting $\frac{s\,h}{d_x^2}$ for N, (see formula **1**) the formula becomes

$$L=\frac{\pi\,s\,h\,(d_0+d_1)}{2\,(d_x)^2}, \qquad (4)$$

Any unit of length may be used in these formulas but for any one problem all quantities must be expressed in the same unit.

EXAMPLE 1.—A relay coil has a winding space 1.75 inches long and .4375 inch deep filled with a wire having a diameter over its insulating covering of 14.2 mils; how many turns has the coil?

SOLUTION.—Substituting the given quantities in formula **1**, the coil contains

$$\frac{1.75\times .4375}{(.0142)^2}=3{,}797 \text{ turns. Ans.}$$

EXAMPLE 2.—If this relay coil has an outside diameter of 1.25 inches and a core .375 inch in diameter, what is the total length of wire on one coil?

SOLUTION.—Substituting in formula 3 gives as the length of wire on one coil

$$\frac{3.1416\times 3{,}797\times(1.25+.375)}{2}=9{,}692 \text{ in., or } 807.7 \text{ ft.}\quad \text{Ans.}$$

66. Determining Resistance of Coil.—The resistance of a coil may be found by multiplying formula 4 by the resistance of 1 inch of the wire, which gives the formula

$$R=\frac{\pi\, r\, s\, h\,(d_0+d_1)}{2\,(d_x)^2},$$

in which R = resistance of coil, in ohms;

r = resistance of 1 inch of wire, in ohms.

EXAMPLE.—A coil has a winding space 1.25 inches long and .219 inch deep filled with No. 22, B. & S. G., double silk-covered copper wire. If the diameter of the core is .469 inch, what is the resistance of the coil?

SOLUTION.—According to Table IV, the resistance of 1 in. of No. 22 B. & S. G. copper wire is $\frac{16.14}{1{,}000\times 12}=.001345$ ohm; and according to Table III, the diameter, over the insulation, of this wire is 29.55 mils, or .02955 in. As $d_1=.469$ and $d_0=.469+2\times.219=907$, substituting in the formula gives as the resistance of the coil

$$\frac{3.1416\times.001345\times 1.25\times.219\times(.907+.469)}{2\times(.02955)^2}=.9114 \text{ ohm.}\quad \text{Ans.}$$

As the wire will imbed somewhat, a trifle more wire might be wound in the given space, giving a little higher resistance.

67. As $\frac{s\,h\,\pi\,(d_0+d_1)}{2}$ is the total volume V, in cubic inches, of the winding space, the resistance formula given in the last article may be written

$$R=\frac{r\,V}{d_x^2}, \qquad (1)$$

in which R = resistance of 1 inch of wire, in ohms;

V = volume of winding space, in cubic inches; and

d_x = diameter of the wire over its insulation, in inches.

If the wire is wound on a spool, the area occupied by each wire will be approximately equal to the square of the diameter and not to $\frac{\pi\, d_x^2}{4}$, because, when the wires are piled over and alongside one another, ca.h wire occupies nearly a square,

each side of which is equal to the diameter of the wire, and the intervening spaces in each corner of each square are almost unoccupied and lost. Hence, the volume divided by the square of the diameter gives the approximate total length of wire. Therefore, the total length $\frac{V}{d_z^2}$, in inches, multiplied by r, the resistance of the wire per inch, gives the total resistance of all the wire on the spool, that is, the resistance of the coil.

When the volume V of the winding space, in cubic inches, and the ohms per cubic inch o of the size wire used are known, the resistance of a coil can be determined from the formula

$$R = V\,o \qquad (2)$$

The diameter of a mean turn is $d_0 - h = d_0 - \frac{1}{2}(d_0 - d_1) = \frac{1}{2}(d_0 + d_1)$; therefore, the length of a mean turn is $3.1416 \times \frac{1}{2}(d_0 + d_1)$. As the depth of the winding on a circular coil is $\frac{1}{2}(d_0 - d_1)$, the area of the winding normal to the core is $3.1416 \times \frac{1}{2}(d_0 + d_1) \times \frac{1}{2}(d_0 - d_1) = .7854\,(d_0^2 - d_1^2)$, and the volume of the space occupied by the winding is $.7854\,(d_0^2 - d_1^2)\,s$. Then the resistance of the coil is

$$R = .7854\,(d_0^2 - d_1^2)\,s\,o \qquad (3)$$

EXAMPLE.—A coil has an outside diameter of .937 inch, an inside diameter of .375 inch, and a winding space .8125 inch long. If it is wound with a wire having a resistance of 34.8 ohms per cubic inch, what is the resistance of the coil?

SOLUTION.—Substituting in formula 3 gives for the resistance of the coil

$$.7854 \times (.937^2 - .375^2) \times .8125 \times 34.8 = 1.663 \text{ ohms. Ans.}$$

68. The resistance of a coil may frequently by obtained from the general formula

$$R = \frac{m\,l\,N}{12\,a},$$

in which R = resistance of coil, in ohms;
m = resistance of mil-foot of wire, in ohms;
l = length of mean turn of coil, in inches;
N = total number of turns;
a = cross-section of bare wire, in circular mils.

A piece of standard annealed copper 1 mil in diameter and 1 foot long (1 mil-foot) has a resistance of 10.37 ohms at 68° F. (20° C.).

EXAMPLE.—A coil wound with No. 17 B. & S. G., double cotton-covered, copper wire has a resistance of .35 ohm at 68° F.; if the length of a mean turn is 3.42 inches, how many turns has the coil?

SOLUTION.—Solving the formula just given for N gives $N=\frac{12\,R\,a}{m\,l}$. As, from Table II, the area of bare No. 17 B. & S. G. wire is 2,050 cir. mils. the coil has

$$\frac{12\times .35\times 2{,}050}{10.37\times 3.42}=243 \text{ turns. Ans.}$$

69. Determining Cross-Section of Wire on Coil.—If the coil is to be used on a fixed voltage E, then the current $I=\frac{E}{R}=\frac{12\,E\,a}{m\,l\,N}$ (see the formula for R in the last article) and the ampere-turns $I\,N=\frac{12\,E\,a}{m\,l}$, hence, the cross-section of the wire, in circular mils, will be

$$a=\frac{m\,l\,I\,N}{12\,E} \qquad (1)$$

For copper wire at 68° F. the value of m is 10.37 ohms, but if the wire is heated until the resistance is increased about 14 per cent., the constant m becomes about 12 ohms, a value frequently used. If $m=12$, the formula becomes

$$a=\frac{l\,I\,N}{E}, \qquad (2)$$

which gives the cross-section in circular mils of the bare wire needed for a given number of ampere-turns when the temperature of the wire is about 138° F., which is often the temperature of coils while in use.

EXAMPLE.—If a magnet having two coils requires 236 ampere-turns for its proper operation on 2 volts, and the mean diameter of the turns is .687 inch, what number B. & S. G. copper wire must be used to wind the coils if they may heat to about 138° F.?

SOLUTION.—The number of ampere-turns for one coil is $\frac{1}{2}\times 236=118$, the voltage across one coil is one-half of $2=1$ volt, and the mean length of the turns is $3.1416\times .687$ in. Substituting in formula 2 gives

$$a=(3.1416\times .687\times 118)\div 1=254.6 \text{ cir. mils}$$

Table IV shows that the nearest corresponding size in the B. & S. G. is No. 26. Ans.

70. Determining Diameter of Bare Wire.—By making no allowance for the thickness of insulation, except that each wire occupies a space of d_x^2 square inches, the diameter of a wire required to fill a winding space having an outside diameter d_0, an inside diameter d_1, and length s, all in inches, and offer a given resistance of R ohms, is given approximately by the formula

$$d=.0287\sqrt{\frac{s\ (d_0^2-d_1^2)}{R}},$$

in which d = diameter of the bare wire, in inches.

This formula may be derived as follows: The total number of turns in a coil is equal to the cross-section of the coil, normal to the direction of the wires, in square inches, multiplied by the number of wires that can cross a square inch. This may be written as follows: Number of turns = number of square inches × wires per square inch. The total length of wire is evidently the total number of turns multiplied by the mean length of one turn. The mean length of one turn is $\frac{\pi}{2}\times(d_0+d_1)$. Hence, the total length of the wire in the coil is the

$$\text{number of square inches}\times\text{wires per square inch}\times\frac{\pi}{2}\times(d_0+d_1).$$

The cross-section of the coil in square inches is $\frac{s\times(d_0-d_1)}{2}$, in which s is the length of the coil; and the number of wires per square inch is $\frac{1}{d_x^2}$, approximately, in which d_x is the diameter, in inches, of the wire over its insulating cover. Then the total length of wire in the coil is

$$\frac{s\times(d_0-d_1)\times\pi\times(d_0+d_1)}{2\times 2\times d_x^2}$$

Now a copper wire $\frac{1}{1000}$ inch in diameter and 1 foot long has a resistance of 10.37 ohms at 68° F., or 20° C.; hence, a copper wire 1 inch in diameter and 1 inch long will have a resistance of $\frac{10.37}{12\times 1{,}000^2}$ ohms, and a copper wire having a diameter of d inches will have a resistance of $\frac{10.37}{12\times 1{,}000^2\times d^2}$ ohms per inch of length.

Then the total resistance of the wire in the coil is, $R=\frac{s\ (d_0-d_1)\ \pi\ (d_0+d_1)\times 10.37}{4\times d_x^2\times 12\times 1{,}000^2\times d^2}$. In order to reduce this to a convenient form, it is necessary to make the approximation that $d_x=d$. This is not a very serious error, especially in this case, where some of the other quantities may not be very exact, and the error reduces as the wire increases in size. Making this approximation, simplifying, and solving for d gives,

$$d=\sqrt[4]{\frac{10.4\times\pi\times s\ \ (d_0^2-d_1^2)}{4\times 12\times 1{,}000^2\times R}},\ \text{or}\ d=.0287\sqrt[4]{\frac{s\ (d_0^2-d_1^2)}{R}}\ \text{inches}$$

Example.—A coil has an outside diameter of 1.12 inches, an inside diameter of .437 inch, the length of winding space 1.875 inches, and a resistance of .6 ohm. With what size wire is it wound?

Solution.—Substituting in the formula gives for the diameter of the bare wire $d=.0287\sqrt[4]{\frac{1.875\ (1.12^2-.437^2)}{.6}}=.0287\sqrt[4]{\frac{1.875\times 1.0634}{.6}}$ $=.0287\sqrt[4]{3.3231}=.0287\times 1.35=.03875$ in. According to Table II, the nearest size wire is No. 18 B. & S. G. Ans.

71. A more exact formula for determining the size of insulated wire to fill a given space is

$$d=\sqrt{i^2+\sqrt{\frac{.7854\ r\ s\ (d_0^2-d_1^2)}{R}}}-i,$$

in which d = diameter of bare wire;

i = radial thickness of insulation;

r = resistance of a wire 1 inch long and 1 inch in diameter,

which is equal to 1 mil-foot divided by $12\times 1{,}000^2$.

The thickness of the insulation i may be obtained from a table by assuming an approximate size for the wire; if not

correct, the formula can be used again with the correct thickness of insulation. The diameter obtained by this formula will not differ much, for wires larger than about No. 30 B. & S. G., from the diameter obtained by the approximately correct formulas previously given. The derivation of several of these formulas are not given here because the reliable authorities from whom they have been selected gave no derivations for them.

72. The bare diameter d of a wire for a coil that will produce $I\,N$ ampere-turns with a given voltage E may be determined from the formula

$$d=\sqrt{\frac{.000001374\,(d_0+d_1)\,I\,N}{E}}$$

After calculating d, the size of the wire that has this diameter may be obtained from a wire table. In order to allow for irregularities in winding, insulation, etc., the next smaller gauge wire should be used, because a length of the smaller wire having the required resistance will not quite fill the space, while, for the next larger size of wire, the spool would not hold enough of the wire to produce the desired resistance, or, strictly speaking, there would not be enough turns.

EXAMPLE.—What will be the number of ampere-turns in a coil, the inside diameter of which is $\frac{3}{8}$ inch and the outside diameter $\frac{7}{8}$ inch, when wound with No. 33 B. & S. single cotton-covered copper wire and having a difference of potential of 8.5 volts across its terminals?

SOLUTION.—From Table IV, the diameter of No. 33 B. & S. wire is 7.08 mils or .00708 inch. Solving the formula just given for the ampere-turns $I\,N$ and then substituting in it, gives

$$I\,N=\frac{d^2\,E}{.000001374(d_0+d_1)}=\frac{(.00708)^2\times 8.5}{.000001374(\frac{7}{8}+\frac{3}{8})}=\frac{.00005013\times 8.5}{.000001374\times\frac{5}{4}}$$
$$=248 \text{ ampere-turns. Ans.}$$

HEATING EFFECT OF CURRENT ON COILS

73. When a current flows through a coil, the coil continues to get hotter and hotter until the amount of heat radiated from the surface of the coil is just equal to the heat being produced in the coil.

Because of the poorer radiation, the inside of a coil is hotter than the outside and a thick coil tends to become hotter than a thin one. In fact, the heating effect of the energy lost in a magnet coil depends on the shape of the coil and on the conditions of ventilation.

For use in telegraph and telephone circuits, a magnet should usually be so designed that it will stand, indefinitely, the full voltage of the circuit without overheating; then, it will not be damaged should a short circuit allow an unusually large current to flow through it. In practice, the radiation from the ends of the coil and from the core may usually be neglected and all the heat is generally supposed to be radiated from the cylindrical surface. This is on the safe side and simplifies the calculations.

74. The safe value that may be allowed for the number of watts radiated from each square inch of cylindrical surface varies generally from .25 to 1.5. If the ventilating conditions are good, a fair value is from .75 to 1 watt for coils at 75° F. above the temperature of the surrounding air. Higher values for the number of watts radiated from each square inch of cylindrical surface can be used only for exceptionally good ventilating conditions or for intermittent-service conditions. As the coils in telegraph and telephone circuits are generally used intermittently, it is usually safe to design a coil so that it will have a sufficient cylindrical surface to radiate 1 watt for each square inch of this surface when the temperature of the coil is 100° F. above that of the surrounding air.

75. Amount of Energy Converted Into Heat.—The number of watts converted into heat and radiated from each square inch of the cylindrical surface of a round coil may be found from the formula

$$w = \frac{W}{3.1416\, d_0\, s}, \qquad (1)$$

in which w = energy radiated per square inch from cylindrical surface of a round coil, in watts;
W = energy expended in coil, in watts;
d_0 = outside diameter of coil, in inches;
s = length of coil, in inches.

The amount of energy W expended in the coil is equal to $I\,E$, $I^2\,R$, or $\frac{E^2}{R}$ watts. By substituting $\frac{E^2}{R}$ for W and solving for R, formula **1** becomes

$$R=\frac{E^2}{3.1416\,d_0\,s\,w}, \qquad (2)$$

in which R = warm resistance of coil, in ohms;
E = voltage across terminal of coil.

To obtain the resistance of the coil at the temperature of the room, allowance must be made for the difference between the temperatures of the room and coil. The resistance of the coil at any desired temperature $t°$ is:

$$R_t=\frac{E^2}{3.1416\,d_0\,s\,w\,[1+a\,(t_1-t)]}, \qquad (3)$$

in which t_1 = temperature of coil, the higher temperature;
t = temperature at which resistance of coil is desired, usually the temperature of room;
a = temperature coefficient of metal of which wire is made.

The temperature coefficient varies somewhat with the temperature, but for practical calculations, as here given, one value is sufficient for all temperatures. When t_1 and t are expressed in Fahrenheit degrees, for copper wire $a = .00218$; when t_1 and t are expressed in centigrade degrees, $a = .00393$.

EXAMPLE.—The outside diameter of a coil is 1.4 inches, its length 2.9 inches, and its temperature is 105° F. If it radiates $\frac{1}{2}$ watt per square inch of cylindrical surface, when operated with a difference of potential of 2.9 volts, what is its resistance at 65° F.?

SOLUTION.—Substituting in formula **3** gives

$$R_{65}=\frac{2.9^2}{3.1416\times1.4\times2.9\times.5\times[1+.00218\times(105-65)]}=\frac{8.41}{3.1416\times2.03\times1.087}$$
$$=1.21 \text{ ohms. Ans.}$$

SUBSTITUTION METHOD OF WINDING

76. Sometimes it is necessary to try one winding to determine its effect in a given circuit and from the knowledge so gained to substitute another better fitted to the conditions.

Suppose, for example, that a given coil for a given core has been wound with No. 28 B. & S. single silk-covered copper wire and that it has a resistance of 100 ohms; but that the conditions of the circuit require the coil to be rewound so as to have a resistance of 900 ohms. As the winding space remains the same and the resistance is to be increased nine times, the wire to be used must have nine times as great a resistance per cubic inch as No. 28 B. & S. From Table IV, it is found that No. 28 single silk-covered copper wire has a resistance of 26.86 ohms per cubic inch. As $9 \times 26.86 = 241.7$ and the wire having the resistance nearest to this is No. 33, which has a resistance of 217.8 ohms per cubic inch, the coil must be wound a trifle fuller to obtain the desired resistance of 900 ohms.

Suppose, also, that a spool is wound with No. 28 single silk-covered wire but that it is necessary for the spool to have double the number of turns it now has. According to Table III, there are 4,014.5 turns per square inch of the given wire; therefore, double this is $2 \times 4{,}014.5 = 8{,}029$ turns. The wire most nearly satisfying this condition is No. 32, which has 8,597.5 turns; therefore, by not quite filling the spool with No. 32 the desired number of turns can be secured.

TELEGRAPHY
(PART 1)

PRIMARY CELLS

ARRANGEMENT OF PRIMARY CELLS

INTRODUCTION

1. Current can usually be produced so much more economically by dynamos and storage batteries that primary cells are not used so extensively as formerly. However, primary cells are still used in many small stations, for which reason the various ways of connecting them should be understood.

In North America the crowfoot, gravity, Daniell, or Calland cell, as it is variously termed, has been very extensively used for main-line and sounder circuits; single stations have had in use 12,000 such cells. For railway signal work, the Edison, Gordon, and Fuller cells have been quite extensively used. For district-messenger, local, and other circuits that are normally open, various forms of Leclanché and dry cells have been used. Some railroads are trying dry cells, which are now quite reliable and cheap, for main-line circuits.

2. Internal and External Circuits.—When a battery constitutes part of a circuit, the battery is not only acting as a source of electromotive force, but constitutes, also, a part of the total resistance of the circuit. Under certain conditions,

this internal resistance of the battery is very effective, and, in some cases, determines the most suitable arrangement of the cells for the production of the proper current strength. That part of a circuit which is external to the cell, or source of electrical energy, is called the **external circuit,** while the remaining part of the circuit, which is included within the cell or source of electrical energy, is called the **internal circuit.**

3. Methods of Joining Cells.—When joining together a number of cells in series, the positive pole of the first cell should be connected with the negative pole of the second, the positive of the second with the negative of the third, and so on throughout the whole series. It matters not with which pole the work is begun, provided care is taken not to connect like poles together. This care must be as strictly observed when joining batteries hundreds of miles apart as when they stand side by side. The method of joining cells in series, parallel, or parallel-series, is explained elsewhere.

BATTERY FORMULAS

4. General Formulas.—In the formulas to follow, let

I = current in circuit;
b = internal resistance of one cell;
B = total internal resistance of battery;
R = external resistance of circuit;
l = resistance of line wire;
r = resistance of all relays in same circuit;
e = electromotive force of one cell;
E = electromotive force of whole battery;
N = total number of cells;
s = number of cells in series in one row;
p = number of rows of cells in parallel.

It is evident that $N = p\,s$ (1)

and that $R = l + r$ (2)

The total electromotive force of a battery depends on the number of cells in series, and, therefore,

$$E = s\,e \qquad (3)$$

5. Obtaining Battery Resistance.—The total internal resistance depends on whether the cells are in series, in parallel, or in a combination of both series and parallel. If all the cells are placed in series, as shown in Fig. 1, the total internal resistance of the battery is

$$B=s\,b \qquad (1)$$

If all the cells are in parallel, as shown in Fig. 2,

$$B=\frac{b}{p} \qquad (2)$$

If the cells are arranged in a combination of both series and parallel, as in Fig. 3,

$$B=\frac{s\,b}{p} \qquad (3)$$

In the arrangement shown in Fig. 3, $s=2$, $p=3$, $N=6$, $E=2\,e$, and the total internal resistance of the battery $=\frac{2\,b}{3}$.

6. Amount of Current.—The current that will flow in any circuit may be calculated from the formulas:

$$I=\frac{s\,e}{\frac{s\,b}{p}+r+l} \qquad (1)$$

$$I=\frac{s\,e}{\frac{s\,b}{p}+R} \qquad (2)$$

Example.—If, in Fig. 4 (*a*) and (*b*), the electromotive force and internal resistance of each cell are 1 volt and 2 ohms, respectively, what current will flow in the circuit?

Solution.—In both diagrams, $s=13$, $p=2$, $r=40$, $l=20$; therefore, by formula **1**, the current is

$$\frac{13\times 1}{\frac{13\times 2}{2}+40+20}=.17+ \text{ ampere. Ans.}$$

This current is sufficient to operate the 20-ohm sounders.

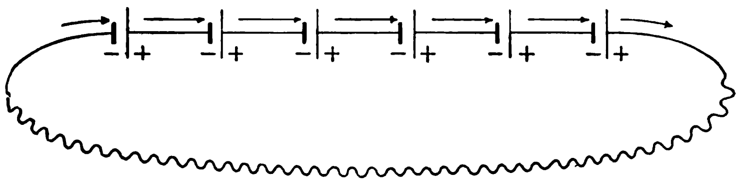


Fig. 1

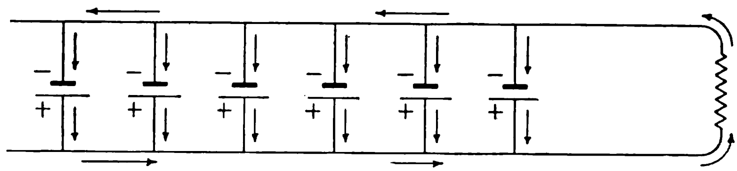


Fig. 2

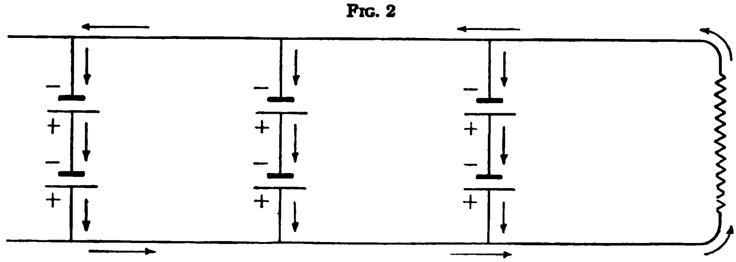


Fig. 3

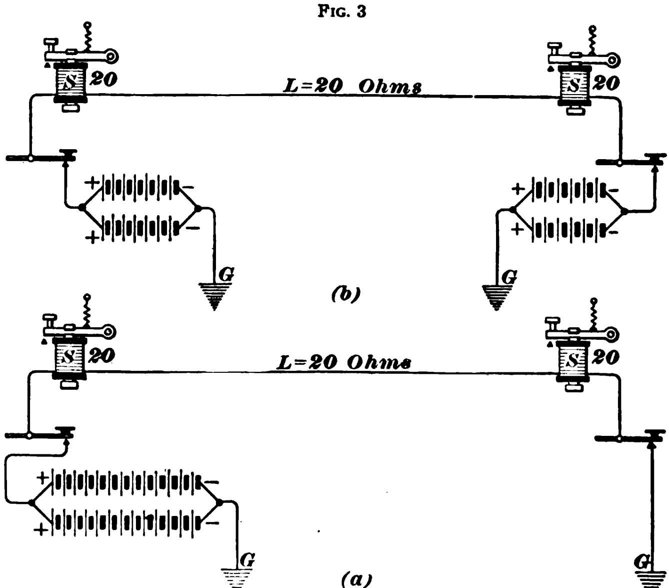


Fig. 4

7. Amount of Current With Small External Resistance.—From formula **2**, Art. **6**, when $R=0$,

$$I=\frac{p\,e}{b}$$

That is, the current is proportional to p, the number of cells in parallel, and is independent of the number in series. From this, it may be seen that, whenever the external resistance is very small and negligible in comparison with the internal resistance of the battery, the number of cells in parallel must be increased in order to increase the current. Increasing the number of cells in series in such a circuit will not increase the current. This is in spite of the fact that the electromotive force increases directly as the number of cells in series increases and remains constant, no matter how many are connected in parallel; for, connecting more cells in series, in this case, increases the total resistance of the circuit as fast as the electromotive force increases, and so the current remains practically constant. On the other hand, if the number of cells in parallel is doubled, the resistance will be reduced to one-half its previous value, but the electromotive force is the same, and, consequently, the current will be twice as great.

8. Amount of Current With Large External Resistance.—When the external resistance R, in formula **2**, Art. **6**, is very large compared with the internal resistance $\frac{s\,b}{p}$ of the battery, then

$$I=\frac{s\,e}{R}$$

In this case, when $\frac{s\,b}{p}$ is entirely negligible in comparison with R, the current is directly proportional to s, the number of cells in series, and is practically independent of the number in parallel. From this, it may be seen that, whenever the external resistance is very large compared with the internal resistance of the battery, the number of cells in series must be increased in order to increase the current. Increasing the number of cells in parallel will not appreciably increase the current, although it does decrease the internal resistance.

9. Summary of Formulas.—These facts may be summarized as follows:

If R is very large compared with $\frac{sb}{p}$,
$$\begin{cases} I = \frac{se}{R}, & \text{when cells are in series.} \\ I = \frac{e}{R}, & \text{when cells are in parallel.} \end{cases}$$

If R is very small compared with $\frac{sb}{p}$,
$$\begin{cases} I = \frac{e}{b}, & \text{when cells are in series.} \\ I = \frac{pe}{b}, & \text{when cells are in parallel.} \end{cases}$$

It may readily be shown, also, that, when the resistance in a circuit is very large, the insertion of an extra relatively small resistance will only decrease the current by a correspondingly small fraction. For instance, suppose the total resistance, including the line, relays, and battery, of a telegraph line is 4,000 ohms and the electromotive force of the battery is 120 volts. How much will the current be decreased by inserting an extra 150-ohm relay at some intermediate station? Originally the current is $120 \div 4{,}000 = .03$ ampere. After inserting the extra relay, the current is $120 \div 4{,}150 = .0289$ ampere. That is, the addition of 150 ohms has only decreased the current between 3 and 4 per cent. To bring the current up to .03 ampere will require only five more cells connected in series with the other cells.

MOST EFFICIENT ARRANGEMENT OF PRIMARY CELLS

10. Maximum Current.—It has been proved that a maximum current is obtained through a given external circuit from a given number of cells, when the external resistance and the grouping of the cells are such that the internal resistance of the battery is made as nearly equal as practicable to the external resistance. That is, so choose s and p that $\frac{sb}{p}$ is as nearly equal to R as practicable. Where a number of cells are so arranged as to give the largest possible current through the circuit, half the energy is expended in the external circuit and the other half in the battery itself.

NOTE.—This can easily be shown in the following manner:

Let W = watts expended in external circuit;

and w = watts expended in battery itself.

Then,
$$W = I^2 R$$

and
$$w = I^2 \frac{s\,b}{p}$$

But, in this case, $R = \frac{s\,b}{p}$; therefore, $W = w$.

The method of making the internal resistance of the cells equal to the external resistance gives a maximum output, but the efficiency is low, and this arrangement is wrong for the rapid working of electromagnets for which the time-constant $\frac{L}{R}$ for the circuit should be small. In this expression, L = inductance and R = resistance of the whole circuit. In order, therefore, to make the ratio $\frac{L}{R}$ small, L being a quantity that cannot conveniently be altered, R should be made large. As R is the total resistance of the circuit, it includes the internal resistance of the battery and the resistance of the connecting wire and all electromagnets connected in series in the same circuit; that is, $R = l + r + B$; the larger B is, the larger will R be.

Even when rapid working does not enter as a consideration, the maximum output solution is not at all economical. The efficiency is not over 50 per cent., because half the energy is used up in heating the battery alone.

11. When the electromotive force and internal resistance per cell are known, the maximum current that can be sent through a given external resistance, and the proper method of arranging the cells can be determined. It has been mathematically proved that the expression $\dfrac{s\,e}{\frac{s\,b}{p} + R}$ (see formula **2**, Art. **6**) has a maximum value, for a given number of cells N, when $\frac{s\,b}{p} = R$. From the latter equation, $s\,b = p\,R$, or $s^2\,b = p\,s\,R$, and $s\,p\,b = p^2\,R$; but $p\,s = N$, $s^2\,b = N\,R$, and $N\,b = p^2\,R$;

whence, $$s=\sqrt{\frac{NR}{b}} \quad (1)$$

and $$p=\sqrt{\frac{Nb}{R}} \quad (2)$$

By substituting in formula **2**, Art. **6**, R for $\frac{sb}{p}$ and the value given for s in formula **1**, and simplifying,

$$I=\frac{e}{2}\sqrt{\frac{N}{Rb}} \quad (3)$$

From formulas **1**, **2**, and **3**, the values of s, p, and I may be calculated when R, b, N, and e are known. If I is known and it is desired to find the total number of cells N, the number in series s, and the number in parallel p, formula **3** may be put into the following form:

$$N=\frac{4I^2Rb}{e^2} \quad (4)$$

Thus, N may be calculated from formula **4**, s from formula **1**, and p from formula **2**, or from formula **1**, Art. **4**. The values so calculated will give the least number of cells and the number to be connected in series and in parallel, in order to furnish a given current.

In working problems with these formulas, the value for N may come out a fraction or a number that cannot be divided into any number of parallel sets, each containing the same number of cells in series. In this case, the nearest larger number that can be so divided should be used.

EXAMPLE 1.—The resistance of a line and all relays is 4,000 ohms. How many cells will be required, and how must they be arranged to give a current of .02 ampere if the electromotive force is 1 volt and the internal resistance 2 ohms per cell?

SOLUTION.—As the internal resistance of all the cells will, evidently, be much less than the external resistance, 4,000 ohms, the formulas derived by assuming that the internal and external resistances are equal will not hold, and would, moreover, if used, give absurd results. Therefore, the cells should be arranged in one series set and p will equal 1. If $p=1$, formula **2**, Art. **6**, reduces to $I=\frac{se}{sb+R}$. Solving for s, $s=\frac{IR}{e-bI}$.

Substituting in this last equation the numerical values for I, R, e, and b, stated in the example, gives,

$$s=\frac{.02\times 4{,}000}{1-.02\times 2}=84 \text{ cells. Ans.}$$

EXAMPLE 2.—Suppose the resistance of the external circuit is 15 ohms and the current required is $1\frac{1}{4}$ amperes; what will be the total number of cells, and how many must be connected in series and how many in parallel, assuming that $e=1$ and $b=2$?

SOLUTION.—By formula **4**, Art. **11**,

$$N=\frac{4\times(\frac{5}{4})^2\times 15\times 2}{1}=187.5 \text{ cells}$$

By formula **1**, Art. **11**, the number in series in each set or row,

$$s=\sqrt{\frac{187.5\times 15}{2}}=37.5;$$

and by formula **1**, Art. **4**, the number in parallel, that is, the number of rows, is $p=187.5\div 37.5=5$.

The arrangement will require, therefore, 190 cells, divided into 5 parallel rows, with 38 cells connected in series in each row. Ans.

12. If the total internal resistance of the whole number of cells that must be connected in a one-series set (in order to give the necessary electromotive force to furnish the required current) is less than the external resistance, it is impossible to arrange the cells in any better way than in a one-series set. This is the case in nearly all main-line circuits where only one or two circuits are supplied from the same battery.

13. When the primary cells are connected in series only, as is generally the case in telegraph circuits, a convenient formula for calculating the number of cells s connected in series is

$$s=\frac{IR}{e-bI}, \qquad (1)$$

in which I = current required in circuit having a resistance of R ohms external to the battery;

e = electromotive force per cell;

b = internal resistance per cell.

For practical work, sounders require $\frac{1}{4}$ watt; hence, the current required by one of any resistance R, but of standard size and construction, may be calculated by the formula:

$$I = \frac{1}{\sqrt{4R}} \qquad (2)$$

EXAMPLE 1.—How many gravity cells having an electromotive force of 1 volt and an internal resistance of 2 ohms per cell must be used to give .04 ampere in a circuit having a resistance of 2,500 ohms external to the battery?

SOLUTION.—Substituting in formula **1**, gives

$$s = \frac{.04 \times 2{,}500}{1 - 2 \times .04} = 109 \text{ cells. Ans.}$$

EXAMPLE 2.—How much current will be required by a standard sized sounder wound to have a resistance of 100 ohms?

SOLUTION.—Substituting in formula **2**, gives

$$I = \frac{1}{\sqrt{4 \times 100}} = .05 \text{ ampere. Ans.}$$

14. Maximum Economy.—The most economical arrangement of cells is not that which gives the maximum current; so far as the consumption of battery material is concerned, it is that in which the internal resistance of the battery is very small compared with the external resistance. The materials of the battery will be consumed slowly and the current will not have its greatest possible strength, but the energy wasted in the battery itself will be a minimum. This, however, will generally require such a large number of cells that the initial cost of the cells and the room occupied by them will entirely prohibit such an arrangement.

15. Generally Accepted Arrangement of Primary Cells.—The plan commonly accepted and heretofore quite generally adopted, has been to make the combined resistance of all telegraph electromagnets, such as relays, main-line sounders, etc. that are connected in series in the same line circuit, equal to the combined resistance of the line and the batteries. This is a more economical arrangement than that in which the maximum current output is obtained. For, in

that case, less than half the energy was consumed in the relays, while, in this case, half the energy is consumed in the relays; hence, a larger proportion of the energy is useful. This arrangement cannot, however, always be adhered to on long lines, especially where there are but few offices on the same circuit, nor is it the best arrangement on long lines having many relays, unless the insulation of the line, even in wet weather, is very good indeed—much better than is usually the case.

There has been a movement, especially on long railway lines, to use lower resistance relays—37.5-ohm relays, for instance—in place of the usual 150-ohm relays. During wet weather and on all poorly insulated long lines with many relays in one circuit, there is great advantage in the use of the lower resistance relays, in spite of the fact that the expenditure of a great deal more electrical energy, at the expense of more cells and the consumption of more battery material, is required. The idea is to expend a greater proportion of the total energy in the line where it can supply the unavoidable leakage losses without reducing the current in the relays too much. The use and advantage of low-resistance relays on long, heavily loaded lines can be better explained after the working efficiency of the line has been treated.

16. To obtain the number of cells in series and in parallel, and the total number of cells to satisfy the condition that the resistance of all relays shall equal the combined resistance of the line and battery, it is necessary to make $\frac{s\,b}{p}+l=r$, then $s=\frac{(r-l)p}{b}$, but $p=\frac{N}{s}$; hence,

$$s=\sqrt{\frac{N\,(r-l)}{b}} \qquad (1)$$

By substituting r for $\frac{s\,b}{p}+l$ in formula **1**, Art. **6**, another expression for s is obtained, namely

$$s=\frac{2\,I\,r}{e} \qquad (2)$$

Substituting these two different expressions for s in $s\,p=N$, two formulas for p are obtained, namely

$$p=\sqrt{\frac{N\,b}{(r-l)}} \qquad (3)$$

and

$$p=\frac{N\,e}{2\,I\,r} \qquad (4)$$

By substituting for s, in formula **2**, the value found for it in formula **1**,

$$I=\frac{e}{2\,r}\sqrt{\frac{N\,(r-l)}{b}} \qquad (5)$$

EXAMPLE.—It is required to send $\frac{1}{4}$ ampere through two 20-ohm magnets and a line having a resistance of 30 ohms. The cells to be used have an electromotive force of 1 volt and an internal resistance of 2 ohms per cell. How many cells will be necessary, and how should they be arranged in order that half the energy may be expended in the relays?

SOLUTION.—Solving formula **5** for N and substituting the values stated in the example, gives

$$N=\frac{4\,I^2\,r^2\,b}{e^2(r-l)}=\frac{4\times(\frac{1}{4})^2\times(40)^2\times 2}{1\times(40-30)}=80 \text{ cells}$$

By formula **1**, Art. **16**, and formula **1**, Art. **4**,

$$s=\sqrt{\frac{80\times(40-30)}{2}}=20$$

and $p=80\div 20=4$. Therefore, 80 cells will be required, arranged in 4 parallel rows of 20 cells each in series. Ans.

If arranged so that half the energy is wasted in the battery, one set of 35 cells connected in series will be sufficient; a set so arranged, however, will not last near so long. Considering the first cost of the additional cells and the extra room required for them, perhaps the arrangement requiring the 35 cells will be more desirable in this case than that requiring the 80 cells.

17. In the case of very long lines, and especially when such long lines have comparatively few relays in their circuits, it is not feasible to make the combined internal and line resistance equal to that of all the relays, for relays of impractically high resistance would be required in order to make $B+l=r$. Thus, if l is very large, it may be practically

impossible to make r equal to l, much less equal to $B+l$. Furthermore, in such a case, the internal resistance of the battery B, even with all the cells in series, would generally be a negligible quantity compared with l. So that in the case of long or high-resistance lines, the cells must all be connected in a one-series set.

A general solution for the best arrangement of primary cells in all cases would be too complicated, even if possible. To determine the best arrangement, the formulas already given must be used with discretion and not blindly. On submarine cables and very long lines, the resistance of the line circuit is already so large that connecting the cells in series does not appreciably increase the total resistance.

TELEGRAPH LINES SUPPLIED FROM ONE BATTERY

18. When primary cells that have an appreciable internal resistance, such as gravity cells, are used, no more than one or two or possibly three lines should be connected to the same set of cells. The more lines that are supplied by the same battery, the more will the current in one line vary as the other circuits are opened and closed. Thus, with many lines connected to one battery, the current in one line may fluctuate so much, when the keys in the other lines are opened and closed, as to operate the relay in the first-mentioned line.

With dynamos and storage cells, the number of lines that may be supplied from the same source is limited only by the output capacity of the dynamo or storage battery. The reason for this lies in the fact that the internal resistance of dynamos and storage cells is extremely small, and especially so in comparison with the resistance of the line circuits.

19. Several Lines Supplied by Same Battery.—Let us consider a general case, as shown in Fig. 5, in which there are three circuits of resistances, x, y, and z ohms, respectively, joined at a common point T and connected to one battery B, consisting of s cells joined together in series.

Let the electromotive force and internal resistance per cell be e volts and b ohms, respectively, and the currents in x, y,

and z be I_x, I_y, and I_z amperes, respectively. The current in each branch circuit, when the other two are open, will be given by the following formulas:

$$I_x = \frac{s\,e}{s\,b + x} \qquad (1)$$

$$I_y = \frac{s\,e}{s\,b + y} \qquad (2)$$

$$I_z = \frac{s\,e}{s\,b + z} \qquad (3)$$

When all three circuits are closed at the same time, the total current flowing out of the battery will be

$$I'_x + I'_y + I'_z = \frac{s\,e}{s\,b + \left(\dfrac{1}{\dfrac{1}{x} + \dfrac{1}{y} + \dfrac{1}{z}}\right)} = \frac{s\,e}{s\,b + \dfrac{x\,y\,z}{x\,y + x\,z + y\,z}} \qquad (4)$$

Then the current in each branch circuit, when all three circuits are closed, will be given by the following formulas:

$$I'_x = \left(\frac{y\,z}{x\,y + x\,z + y\,z}\right)\left(\frac{s\,e}{s\,b + \dfrac{x\,y\,z}{x\,y + x\,z + y\,z}}\right) \qquad (5)$$

$$I'_y = \left(\frac{x\,z}{x\,y + x\,z + y\,z}\right)\left(\frac{s\,e}{s\,b + \dfrac{x\,y\,z}{x\,y + x\,z + y\,z}}\right) \qquad (6)$$

$$I'_z = \left(\frac{x\,y}{x\,y + x\,z + y\,z}\right)\left(\frac{s\,e}{s\,b + \dfrac{x\,y\,z}{x\,y + x\,z + y\,z}}\right) \qquad (7)$$

NOTE.—A current will divide among the various paths between two points inversely as the resistances of the paths; hence, formula **5** follows from the proportion

current in 1 branch		total current		total resistance		resistance of 1 branch
I'_x	:	$\dfrac{s\,e}{s\,b + \dfrac{x\,y\,z}{x\,y + x\,z + y\,z}}$	=	$\dfrac{x\,y\,z}{x\,y + x\,z + y\,z}$	:	x

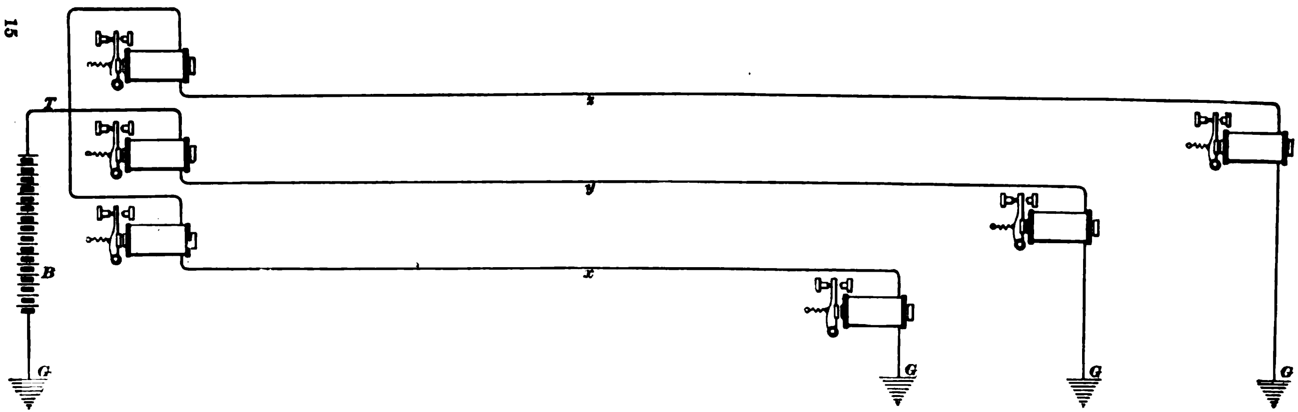


Fig. 5

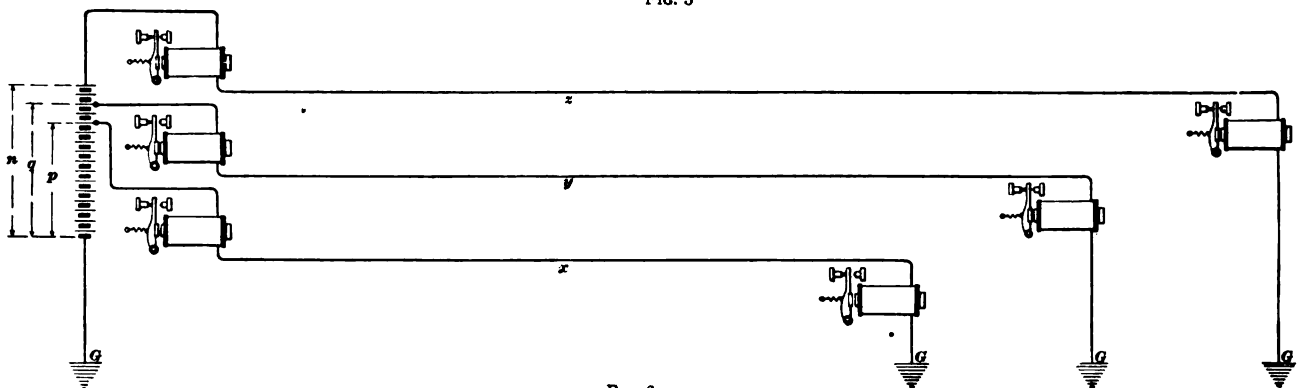


Fig. 6

20. Now, it is desirable that the strength of the current in any line shall not change too much as the other circuits are opened and closed. In other words, it is desirable to have $I_x = I'_x$, $I_y = I'_y$, and $I_z = I'_z$, or the differences $I_x - I'_x$, $I_y - I'_y$, and $I_z - I'_z$ so small that they will not cause serious trouble in any of the circuits. Evidently, as b or $s\,b$ approaches zero, that is, becomes smaller and smaller, the value for I'_x given in formula **5,** Art. **19,** approaches that given for I_x in formula **1,** Art. **19,** and, when b becomes zero, $I_x = I'_x$, $I_y = I'_y$, and $I_z = I'_z$. Consequently, when $b = 0$, the strength of the current in any one line will remain the same theoretically, no matter how many circuits are joined in parallel with it. In other words, when two or more circuits are connected in parallel with one another, and all are joined to the same terminal of one battery, the current in any line would be unaffected when one or all the other circuits are opened or closed, only if the internal resistance of the battery could be made equal to zero, or infinitely small in comparison with that of the several parallel circuits. And the larger $s\,b$ becomes in comparison with the external resistance, the more will the current strength in any one circuit fluctuate as one or all the other parallel circuits are opened or closed.

21. If cells having an appreciable internal resistance are in use, increasing the number of cells in series as the number of parallel circuits to be worked by this one battery is increased, is not the correct thing to do. For, while the total external resistance is being decreased by the addition of parallel circuits, the internal resistance is being increased by the addition of more cells in series, and, consequently, the strength of the current in any one line will fluctuate more than ever as the other circuits joined in parallel with it are opened and closed. It is better to decrease the internal resistance of the whole battery by increasing the number of parallel rows of cells, and not by increasing the number of cells in series.

EXAMPLE.—There are three line circuits, having resistances of 3,000, 3,500, and 4,000 ohms, respectively, to be supplied from one battery. Gravity cells having an electromotive force of 1 volt and an internal resistance of 2 ohms per cell are to be used. (*a*) What will be the number

of cells required to give .05 ampere in the 4,000-ohm circuit when it alone is closed? (*b*) What will be the current in the 4,000-ohm circuit when the other two circuits are also closed?

SOLUTION.—(*a*) The number of cells required to supply .05 ampere to the 4,000-ohm circuit when it alone is closed can be determined by substituting the values given in the example in formula **1**, Art. **19**, and then solving for s. Doing this, $.05=\frac{s}{2\,s+4{,}000}$, from which $s=222$ cells. Ans.

(*b*) When all three circuits are closed the current in the 4,000-ohm circuit will be given by formula **5**, Art. **21**,

$$I'_x=\left(\frac{3{,}000\times3{,}500}{4{,}000\times3{,}500+4{,}000\times3{,}000+3{,}500\times3{,}000}\right)$$
$$\times\left(\frac{222}{444+\frac{4{,}000\times3{,}500\times3{,}000}{4{,}000\times3{,}500+4{,}000\times3{,}000+3{,}500\times3{,}000}}\right)=.04 \text{ ampere. Ans.}$$

When, therefore, the other two circuits are also closed, the current in the 4,000-ohm circuit decreases from .05 to .04, or 20 per cent.

It would be best to employ separate batteries in such a case, but the example has been worked out in order to show how much the current will decrease in the one line after the other two circuits are closed.

22. To Obtain Same Current in Each Branch Circuit.—Where a number of line circuits contain the same resistance relays, about the same current is needed in each circuit. Where the several lines are joined to the same terminal of the same battery, this can only be obtained by inserting enough extra resistances, in all but the one having the highest resistance, to make the resistances of all equal. When several lines must be worked from the same pole of the same battery, the current in one line will fluctuate less if all the circuits have the same resistance.

EXAMPLE.—Taking the same circuit as in the example just given, suppose it is desired to have .0416 ampere in each circuit when all three circuits are closed. (*a*) How many cells will be required in a one-series set? (*b*) What will be the current in one circuit when only that one circuit is closed? (*c*) By what per cent. will the current change in value?

SOLUTION.—(*a*) There must be inserted in the 3,000-ohm circuit 1,000 ohms, and in the 3,500-ohm circuit 500 ohms, in order to bring each up

to 4,000 ohms. The number of cells s required may be determined by substituting in formula **5**, Art. **19**, the values given and solving for s,

$$.0416=\frac{1}{3}\left(\frac{s}{2s+\frac{4,000}{3}}\right)$$

from which $s=222$ cells. Ans.

(*b*) When only one circuit is closed, the current in that circuit will be

$$I_x=\frac{222}{444+4,000}=.05 \text{ ampere. Ans.}$$

(*c*) The current in one line has therefore changed about 17 per cent. instead of 20 per cent., as in the preceding example. This smaller change in the current is due to the fact that the combined resistance of the three lines in parallel is greater in the last example, and, therefore, the internal resistance of the battery is a smaller proportion of the whole resistance. Ans.

A better way in which to connect the three lines to one common battery is to connect the 4,000-ohm line across the whole battery, and the 3,500- and 3,000-ohm lines at such intermediate points as will give the necessary electromotive force to supply the current desired in each branch circuit. Fig. 6 shows three lines arranged in this manner.

23. The expressions given in Art. **19** for the currents I_x, I_y, and I_z in each circuit when the other two circuits are open, may be put into the following form, in which p, q, and n represent the number of cells between each line and the ground. $I_x=\frac{e}{b+\frac{x}{p}}$, $I_y=\frac{e}{b+\frac{y}{q}}$, $I_z=\frac{e}{b+\frac{z}{n}}$. From these equations, it is evident that $I_x=I_y=I_z$, when $\frac{x}{p}=\frac{y}{q}=\frac{z}{n}$. Therefore, if an equal current is wanted in each line circuit, the lines must be joined to the battery at such points that the relation $\frac{x}{p}=\frac{y}{q}=\frac{z}{n}$ is satisfied. In other words, if the same current is wanted in each circuit, the lines should be attached to the battery at such points that the number of cells by which a line is worked has the same relation to the resistance of that line as the whole number of cells has to the resistance of the longest line.

EXAMPLE.—In the case of three line circuits having resistances of 3,000, 3,500, and 4,000 ohms, respectively, at what points in one common battery of 222 cells should the circuits be joined in order to have the same current in any one when the other two circuits are open? The longest line (4,000 ohms) is to be connected across all the cells.

SOLUTION.—The lines must be joined to the battery at such points that the relation $\frac{x}{p}=\frac{y}{q}=\frac{z}{n}$ shall be satisfied. Then, $\frac{3{,}000}{p}=\frac{3{,}500}{q}=\frac{4{,}000}{222}$. By solving this, $q=194$ and $p=167$. That is, between the ground and the circuit x, there must be 167 cells, and between the ground and the circuit y, 194 cells. Ans.

NOTE.—The expressions for the current in each circuit in Fig. 6 when all three circuits are closed are very complicated, and the problem has no practical value. Consequently, for this case, no expressions for the current in each circuit have been given.

24. Effect of Leakage.—Theoretically, the arrangement indicated in the example in Art. 23 is correct, but there is more leakage on the longer lines; that is, a larger percentage of the current that starts on the longer line leaks to the ground without going through the distant relay where the battery is all at one end, or through the middle of the line in case one-half the battery is at each end. Consequently, the longer the line, the larger must be the current from the battery, in order to have the desired current at a certain distant place, and, hence, the electromotive force on the longer lines must be somewhat greater to make up for the increased leakage. That is, if p and n were made to satisfy the equation $\frac{x}{p}=\frac{z}{n}$, and there was much more leakage on the line z than on x, then, practically, n would be too small compared to p, and the currents in the two lines would not be equal at certain distant points on the two circuits, as intended.

EXAMPLE.—A telegraph circuit of 4,000 ohms resistance is supplied with current from 222 cells connected in a one-series set at one end of the line. Assume the electromotive force and internal resistance of each cell to be 1 volt and 2 ohms, respectively. (*a*) What will be the current when there is no leakage? (*b*) What will be the current when only 70 per cent. of the total current reaches the far end? (*c*) What will be the percentage increase in the total current and the percentage decrease in the current at the far end when the leakage increases so that only 70 instead of 100 per cent. of the current reaches the distant office?

SOLUTION.—(*a*) When there is no leakage, the current throughout the circuit will be $\frac{222}{444+4{,}000}=.05$ ampere. Ans.

(*b*) As the leakage path is a circuit in parallel with more or less of the line circuit, it may be assumed to be in parallel with the whole line circuit. Then, according to the law for branch circuits, the resistances of the leakage path and line circuit will be to each other inversely as the currents through each. Hence, the resistance of the leakage path will be $\frac{70}{30}$ of 4,000, which is $\frac{28{,}000}{3}$ ohms. The total resistance of the circuit is equal to

$$\frac{\frac{28{,}000}{3}\times 4{,}000}{\frac{28{,}000}{3}+4{,}000}+444=3{,}244 \text{ ohms}$$

Then, 70 per cent. of total current is equal to $\frac{7}{10}\times\frac{222}{3{,}244}=.0445$ ampere. Ans.

(*c*) The total current is equal to $222\div 3{,}244=.0684$ ampere. Thus, the total current, .0684, is 37 per cent. greater than .05, but, nevertheless, the current through the distant relay, .0445, is 11 per cent. less than the current, .05, when there was no leakage. Ans.

25. The preceding articles show how necessary it is to employ cells of low internal resistance where one battery is used to supply more than one or two lines, if it is desired to avoid a fluctuating current in each line circuit as the others are opened and closed. The internal resistance may be reduced by coupling more cells in parallel, or by using cells having a lower internal resistance. For the latter reason, one of the great advantages of storage batteries and dynamos for supplying current to a large number of telegraph circuits is apparent. Furthermore, during wet weather, the resistance of all the lines may not only decrease considerably, but some may decrease a great deal more than others. Consequently, if several lines are supplied from one battery having an appreciable internal resistance, and if the leakage current on one line increases more in proportion than on the others, due to wet weather, partial grounds, or crosses, then the division of the current among the several branch circuits will be greatly altered, especially when the resistance of the line on which

there is most leakage is small. The variation in the current in the good lines will be proportional to the amount of leakage on the defective lines. When the leakage on several lines is not about proportional to their lengths, those on which the leakage is extra large should be worked by separate batteries.

EXAMPLES IN CELL ARRANGEMENT

26. In some places examinations are given to determine the fitness of telegraph employes for advancement and increase in salary. The following examples are taken from such examinations and require for their solution only such information as has been given so far. To test one's ability to solve them, each example should be worked out before the solution is read, or any assistance obtained from it.

EXAMPLE 1.—If two batteries of 30 and 50 gravity cells of similar voltage and internal resistance have the cells connected in series, and each battery is short-circuited, how may the relative values of the current in each circuit be found?

SOLUTION.—If e is the electromotive force and b the internal resistance of each cell, and the external resistance is 0, due to the batteries being short-circuited, then according to Ohm's law, the current in the circuit consisting of 30 cells is $\frac{30\times e}{30\times b}=\frac{e}{b}$, and in the circuit consisting of 50 cells is $\frac{50\times e}{50\times b}=\frac{e}{b}$; that is, the current is the same in each case.

EXAMPLE 2.—How many cells having an electromotive force of 1.46 volts and an internal resistance of 2.8 ohms, when connected in series, will be required to send a current of 18 milliamperes through an external resistance of 2,456 ohms?

SOLUTION.—The current flowing in the circuit is $I=\frac{s\,e}{s\,b+R}$, in which s = number of cells required, $e=1.46$ volts, $b=2.8$ ohms, $R=2{,}456$ ohms, and $I=.018$ ampere. Solving for s and substituting the known values, gives $s=\frac{I\,R}{e-I\,b}=\frac{.018\times 2{,}456}{1.46-.018\times 2.8}=\frac{44.208}{1.46-.05}=31.3$; that is, 32 cells will be required.

EXAMPLE 3.—Two batteries are joined in parallel; one has an electromotive force of 40 volts and an internal resistance of 160 ohms, the other

has an electromotive force of 36 volts and an internal resistance of 90 ohms; what is the potential difference at their points of juncture?

SOLUTION.—The two electromotive forces oppose each other, leaving $40-36=4$ volts to send a current of $\frac{4}{160+90}=.016$ ampere through the circuit containing both sets of cells. Therefore, the loss through one set is $.016\times160=2.56$ volts, giving $40-2.56=37.44$ volts at its terminals. This set being the more powerful causes .016 ampere to flow through the 36-volt battery in opposition to its electromotive force; hence, the difference of potential due alone to this current and the internal resistance of 90 ohms is $.016\times90=1.44$ volts. This added to the electromotive force of the 36-volt battery gives 37.44 volts, which gives exactly the same voltage, as it should, across the terminals of the 36-volt battery as across the 40-volt battery. Ans.

EXAMPLE 4.—With 20 cells, each having an internal resistance of 1.8 ohms and an electromotive force of 1.4 volts, and an ammeter of 2 ohms resistance, what combination of cells will give the largest deflection of the ammeter and what current will be passing through the ammeter, assuming the current to be constant and that the ammeter needle will not be deflected to the stop or off the scale?

SOLUTION.—The largest deflection is produced by the largest current, which flows when the internal and external resistances are as nearly equal as practicable. The total internal resistance should therefore be about 2 ohms. The internal resistance of p rows of cells having s cells in series in each row is $\frac{s\times1.8}{p}=2$, but $s\times p=20$; hence, $s=\frac{20}{p}$ and $\frac{20}{p}\times\frac{1.8}{p}=2$, or $36=2p^2$, therefore $p=4+$. With 4 rows of 5 cells each, the internal resistance is $\frac{5\times1.8}{4}=2.25$ ohms. The total resistance is $2.25+2=4.25$ ohms; the total electromotive force is $5\times1.4=7$ volts, and the greatest current is $7\div4.25=1.65$ amperes. Four rows of 5 cells each and a maximum current of 1.65 amperes are required. Ans.

EXAMPLE 5.—(*a*) A galvanometer having a negligibly small resistance has its scale graduated with divisions representing proportional increases of current. What must be the electromotive force and internal resistance of each cell in order that 2 cells in series with 300 ohms will give a deflection of 100 divisions, and on removing the 300 ohms resistance, give a deflection of 200? (*b*) Can there be such a cell?

SOLUTION.—(*a*) As the current in the second arrangement is twice that in the first, the total resistance of the circuit in the first arrangement must be twice that in the second; that is, $2\times$internal resistance of one cell$+300=2\times2\times$internal resistance of one cell; hence, the internal resistance of one cell is $300\div2=150$ ohms. In the first arrangement the

current $I = \frac{2 \times e}{2 \times 150 + 300}$; in the second arrangement, $I' = \frac{2 \times e}{2 \times 150}$, in which e is the electromotive force of each cell. Now, $I' = 2 \times I$; hence, $\frac{2 \times e}{300} = 2 \times \left(\frac{2 \times e}{600}\right)$. Any value for e will satisfy this equation; hence, the cells have an internal resistance of 150 ohms each and any electromotive force. Ans.

(*b*) No, because no cell could have any electromotive force and no cell in use today has such a high internal resistance as 150 ohms when in good working condition. Ans.

EXAMPLE 6.—A galvanometer of 5,380 ohms resistance is connected in series with 55 Leclanché cells, each having an electromotive force of 1.5 volts and an internal resistance of 2 ohms. What is the resistance and multiplying power of the shunt that should be placed around the galvanometer and the extra resistance to be placed in series in the circuit, so that the galvanometer, its shunt, and extra resistance will still be equal to the galvanometer resistance alone, and the current passing through the shunted galvanometer will be 3.009 milliamperes? The multiplying power of a shunt is the number by which the current in the galvanometer must be multiplied to give the total current produced by the battery.

SOLUTION.—If S represents the shunt resistance and A the extra resistance, then $5{,}380 = \frac{5{,}380 \times S}{5{,}380 + S} + A$. The multiplying power of the shunt is $\frac{5{,}380 + S}{S}$. The current through the galvanometer is .003009 ampere. The total current produced by the battery in the main circuit is $.003009 \times \left(\frac{5{,}380 + S}{S}\right)$. Furthermore, the electromotive force developed by the battery is 55×1.5, the internal resistance of the battery is 55×2, and the total resistance of the circuit is $55 \times 2 + \frac{5{,}380 \times S}{5{,}380 + S} + A$. The current produced in the main circuit by the battery is $(55 \times 1.5) \div \left(55 \times 2 + \frac{5{,}380 \times S}{5{,}380 + S} + A\right)$. The current in the main circuit must be the same by both methods of calculation; hence, $.003009 \times \left(\frac{5{,}380 + S}{S}\right) = \frac{55 \times 1.5}{55 \times 2 + \frac{5{,}380 \times S}{5{,}380 + S} + A}$. But, $\frac{5{,}380 \times S}{5{,}380 + S} + A = 5{,}380$; hence,

$$.003009 \times \left(\frac{5{,}380 + S}{S}\right) = 82.5 \div (110 + 5{,}380).$$

Solving for S gives $\frac{16.1884 + .003009\,S}{S} = \frac{82.5}{5{,}490}$, or $16.1884 \times 5{,}490 + .0003009\,S \times 5{,}490 = 82.5\,S$, or $16.1884 \times 5{,}490 = S\,(82.5 - .003009 \times 5{,}490)$,

or
$$S = \frac{88,874.4}{82.5 - 16.5194} = 1,347 \text{ ohms. Ans.}$$

Then, $A = 5,380 - \frac{5,380 \times 1,347}{5,380 + 1,347} = 5,380 - \frac{7,246,860}{6,727} = 4,303$ ohms. Ans.

The multiplying power of the shunt is
$$\frac{5,380 + 1,347}{1,347} = 4.99. \text{ Ans.}$$

EXAMPLE 7.—A low-resistance cell is placed in circuit with one coil of a differential galvanometer, the deflections of which are proportional to the current, and a small deflection is observed; both coils are then put in circuit and the deflection remains unaltered; another change in the way of coupling the coils is made and the deflection is doubled. Explain what has been done in each case and the cause of the respective indications.

SOLUTION.—A differential galvanometer is an ordinary reflecting galvanometer having two windings of exactly the same number of turns, resistance, and location with respect to the deflecting system. The resistance of one coil is usually high compared with the internal resistance of a low-resistance cell, hence the current will be practically proportional to the resistance of the coils, which in this case constitute the sole external resistance. In the second arrangement, both coils were connected in series, thereby doubling the resistance and number of turns and halving the current. Hence, the product of the current and number of turns is the same in the first two arrangements and consequently the deflections were the same. In the third arrangement, the coils were connected in parallel, thereby halving the resistance and doubling the total current; but only half the total current will flow in each coil, thus the ampere-turns in each coil are the same as in the first case, and hence the total ampere-turns of both coils are twice as great as that in the first arrangement and consequently the deflection is doubled.

EXAMPLE 8.—How may the internal resistance of a battery be determined with a voltmeter of infinite resistance (for instance, an electrostatic voltmeter) and a set of accurate coils whose resistance are known?

SOLUTION.—A modification of the volt-and-ammeter method may be used as follows: First determine the electromotive force of the battery on open circuit by connecting the voltmeter across its terminals; let this reading be E volts. With the voltmeter still connected across the battery terminals connect in series with the battery, the proper amount of known resistance to allow about the normal working current to flow from the battery. The current I is equal to the reading of the voltmeter E' thus obtained, divided by the resistance R in the known coils used; that is, $I = \frac{E'}{R}$. The internal resistance of the battery is $\dfrac{E - E'}{\frac{E'}{R}} = \dfrac{R(E - E')}{E'}$.

PROTECTING DEVICES

LIGHTNING ARRESTERS

27. A **lightning arrester** is a device designed to protect telegraph offices and their instruments from injury, during lightning storms, due to atmospheric electricity, which, when it charges or strikes the line wires, follows them into the offices. If unprotected, the fine-wire coils of instruments would often be burned out, and the operators might also be injured, fatally or otherwise.

The **plate,** or **static, arrester** consists of a plate, block, or disk of metal or carbon separated and insulated from another plate or block of similar material by 5 to 10 mils of insulating material, such as mica, silk, or paraffined paper. One plate, block, or disk is connected to the line and the other to the ground. The lightning discharge passes from the line plate through the insulating material to the grounded plate and then to the earth. Mica is probably the best insulating material for this purpose, as it does not carbonize. Sometimes the mica has holes punched through it or a part of it is cut away. When used, carbon is generally in the form of small blocks about $1\frac{1}{4}$ inch by $\frac{3}{8}$ inch by $\frac{1}{4}$ inch. Two such blocks and a perforated piece of mica to go between them are shown in Fig. 7.

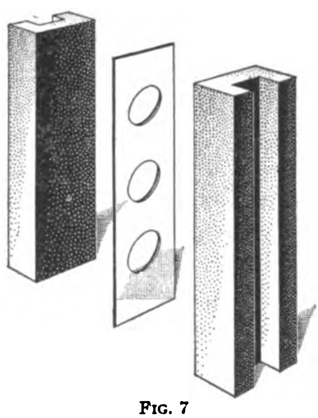


Fig. 7

For protection against lightning only, some advocate the use of copper in place of carbon blocks as the copper blocks are free from the trouble caused by carbon dust and particles.

Copper blocks should not be used where there is danger from crosses with high-potential circuits. In damp places where carbon absorbs moisture, or sweats, mica is put between the carbons and the edges painted with a special compound. This compound is a secret of the manufacturing company, but probably is a camphor solution of pyroxiline. They will then even stand immersion in water for 48 hours. The metal-plate arrester has been extensively used by telegraph companies and the carbon-block arrester is extensively used by both telephone and telegraph companies. They are built in a great variety of forms.

28. Action of Lightning Arresters.—The resistance offered by an air gap between two conducting plates, or between the points of two conductors is the same for alternating currents of high or low frequency as it is for steady direct currents, because an air gap possesses no inductance. But lightning discharges are generally considered to be oscillatory in character, that is, the current surges back and forth thousands of times per second; consequently, a coil of wire, especially when wound on an iron core, has an apparent resistance that is enormously greater for such an oscillatory current than for a steady direct one. The excess resistance that a coil of wire offers to an alternating current over a direct current is due to that property of the coil called its *inductance*. For a given coil and a given intensity of the magnetic flux, the inductance L is constant, but the apparent resistance opposing the current increases rapidly as the number of alternations of the current per second increases. That is, the higher the frequency of alternation, or the greater the rapidity of a change in strength of the current, the greater will be the so-called apparent resistance of the coil of wire.

29. To a steady direct current, the resistance of a given circuit is found, by Ohm's law, to be $R=\frac{E}{I}$. But when E and I are alternating in character, the relation between E and I is so changed that the quotient $\frac{E}{I}$ no longer gives the value for

the resistance just found, but gives some other value, which may be called Z. For a simple alternating current the value of Z may be found from the formula:

$$Z = \sqrt{R^2 + (2\,\pi\,n\,L)^2}$$

in which R = ordinary resistance that circuit would offer to a steady direct current;
L = inductance of circuit;
$\pi = 3.1416$;
n = frequency.

30. The frequency is the number of complete cycles per second, or twice the number of alternations per second. This quantity $\sqrt{R^2+(2\,\pi\,n\,L)^2}$ is called the *impedance* of the circuit whose simple resistance is R and whose inductance is L for an alternating current whose frequency is n. The value of this expression evidently increases if any one of the quantities R, n, or L increases, and, conversely, decreases if any one of them decreases. For a lightning discharge, n is very large, but, for an air gap, even if the air space is replaced with mica or any insulating material, L is zero. Consequently, the impedance of the air gap is always equal to R, no matter how large n is, because $2\,\pi\,n\,L$ is zero when L is zero. Therefore, $\sqrt{R^2+(2\,\pi\,n\,L)^2} = R$ when $L=0$. But for the coils on the instrument, the inductance L has an appreciable value; it may amount to 5 henrys or even more. Consequently, when n has a very large value and L is not too small, the value of $\sqrt{R^2+(2\,\pi\,n\,L)^2}$ will be very large, and, as a matter of fact, n is large enough in lightning discharges to make the value of R^2 generally insignificant compared to $(2\,\pi\,n\,L)^2$. Therefore, for a lightning discharge the impedance of the air gap remains equal to R, because L is zero, as already stated; but the impedance of the coils of wire on the instruments increases so much in value that the air gap becomes, for a lightning discharge, a path of low resistance in comparison with it, and, consequently, since a current will always take the easiest path, the discharge will jump the air gap in its effort to reach the ground in preference to going through the coils on the instruments.

31. This is a very fortunate property of lightning, for, if it were compelled to go through a coil to earth, it would invariably burn out the fine wire in the coil and also ground the coil to the iron core. It would thus ruin the coil, and, in its effort to reach the ground, probably do a great deal more damage.

Direct- and low-frequency currents will not jump the air gaps between any of the plates, because the difference of potential is not usually great enough, and because to them the coils offer an easier path. The electromotive forces of lighting and power circuits, usually under 350 to 400 volts, and against which the telegraph wire may come into contact, are not usually high enough to start an arc across the air gap. Some claim that lightning discharges are not always oscillatory or alternating in character, but even if so, the current strength varies at such a high rate that a coil would still offer great impedance to such a current.

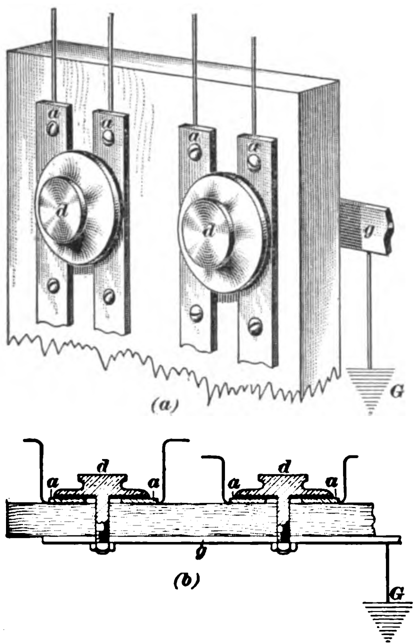


FIG. 8

32. Button Plate Arrester.—In Fig. 8 (*a*) is shown a **button plate arrester** as it is mounted at the top of a way-station switch. In (*b*) is shown a cross-section through the center of the buttons *d*. The metallic disks or buttons *d* overlap, on the front of the board, the vertical straps *a*, to which the line wires are attached, but are insulated from them by paraffined paper or thin pieces of mica. These buttons have screws that pass through the board and into a grounded

plate *g* that runs horizontally along the back of the board, so that all buttons screw into the same plate. The distance between the line plates and the grounded buttons *d* can be adjusted and the buttons removed for cleaning and for the insertion of fresh paraffined paper or mica washers between them and the line plates *a*. A lightning charge coming in over a line will jump from the vertical line strap, through the thin insulating washer, to the button, and then pass through the grounded plate *g* on the back of the board to earth *G*.

33. Brach Arrester.—The essential feature of the **Brach static arrester** consists of a solid composition separating two carbon blocks. The manufacturers claim that this special composition has a low dielectric strength, but a high specific resistance. It should, therefore, be easily punctured by high voltages, but have a very high resistance to low-voltage currents. The material used is composed of silica mixed with high-resistance clays and forming a porous mass through which the discharge takes place. The silica particles act as a conductor and the clay as an insulator. The advantage claimed for this arrester is the assurance of its remaining intact after a discharge and keeping the line free from grounds at the arresters. The material between the carbons fuses only at an exceptionally high temperature and is not affected unless an arc is maintained by a cross with a high-potential circuit, for protection against which a fuse should be used. Both the arrester and the combination arrester and fuse are made in unit types; that is, one unit can be added alongside another for any number of circuits and the ground plates will all be automatically placed in contact. The base of the arrester unit is 1 inch by 4 inches and the base of the combination unit, including the arrester and a short enclosed fuse, is 1 inch by 6 inches. This arrester has been in service on block-signal circuits for 2 or more years and has given satisfactory service. A number have more recently been put in service on telephone lines and there seems no reason why their use should not clear railway telephone and toll lines of the trouble caused by minute static discharges and still keep the line clear of grounds.

34. O'Connell Arrester.—The **O'Connell arrester** is said to have proved quite efficient on train-despatching circuits, on which it has been quite extensively used. It consists of two large, V-shaped, carbon blocks so placed that two edges nearly meet along the top from which edge the surfaces recede from each other. It not only allows a small potential to discharge across the edges near together, but it is able to take care of heavy discharges and tends to blow the arc out along the more widely separated surfaces, and the carbon dust can readily fall down and out of the space between the carbons.

35. Vacuum Arresters.—An American and a German firm are making an arrester with the spark-gap elements placed in a sealed glass vessel from which much of the air has been exhausted. The discharge takes place in the form of a multitudinous or brush-like discharge across the partial vacuum between the two carbon blocks. One form is shown in Fig. 9 (*a*) and another form in (*b*). At a potential difference of 300 or more volts across its terminals *f* and *g* in (*a*) and *i* and *j* in (*b*), a brush discharge between the carbon blocks *a* and *b* will free the circuit of the static strain and yet not lower the insulation; hence, earth-current disturbances on a telephone circuit due to a partial ground occurring after a discharge are avoided and the arrester is in as good condition after a discharge as before.

The arrester is made in cartridge form with one terminal on each end of the glass cylinder, so that it can be readily inserted or removed from the spring sockets *c* and *d*. Each arrester also possesses a screw-point arrester *e*, which may be set to take extra heavy discharges, or screwed up to close the circuit while a defective cartridge is being replaced with a good one. These arresters are also mounted two on one porcelain base with a heat coil alongside each one for use on complete metallic telephone circuits.

36. The form shown in Fig. 9 (*b*) is recommended where aerial lines require protection before entering a building. The arrester cartridge is inserted in a bell-shaped insulator *h* provided with suitable terminals *i* and *j* for attaching to the line and earth wires. The insulator *k* takes the pull of the line wire

and provides an excellent method of connecting, at *m*, the bare line wire to the insulated wire that enters the building.

This vacuum arrester is used in Germany to protect the Pupin load coils from static discharges. Two are connected in series around each coil and the center carbons are connected

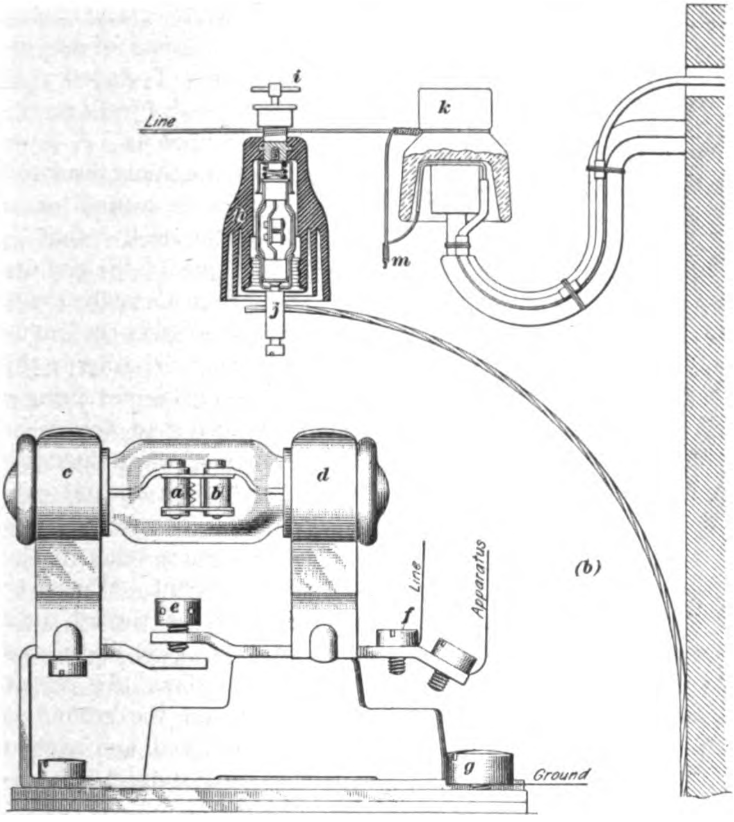


FIG. 9

to ground. The same arrangement, with or without fuses and heat coils properly associated with the arrester, is used on aerial metallic circuits to protect telephone apparatus and cable conductors. The vacuum type of arrester should prove suitable for protecting train-despatching telephone and signal circuits.

37. Protective Device for Relays.—In sections where lightning is especially troublesome, it is desirable to protect more thoroughly certain relays used in duplex and quadruplex systems that are wound with fine wire, and hence easily damaged. For this purpose the device shown in Fig. 10 is used in some telegraph offices. It consists of an inverted **T**-shaped post *a b* with a nut *c* screwing upon it. A layer of fine thinly insulated wire is wound on a metal shell *f* that is permanently connected to ground *G*. The ends of the coil are connected to insulated metal legs *d* and *e* that normally touch the springs *m* and *n*, one of which is connected with the multiplex relay to be protected against lightning and the other to the wedge cord. The line current must now pass from one spring *n* through the coil on the grounded iron shell *f* to the other spring *m*. A lightning discharge encountering the inductance in this coil, will break through the thin insulation and pass through the iron shell *f* to ground rather than pass on through the highly inductive winding of the multiplex relay. The operation of the arrester usually opens the circuit. Whenever this occurs the nut *c* on the arrester should be turned until the end piece *a* is forced against the two springs *m* and *n* and also pushes them away from the legs *d*, *e*. Thus the circuit is closed directly from *n* through *a* to *m* and the ground is removed. The punctured coil can be removed and a good one substituted for it while the circuit is maintained in working order.

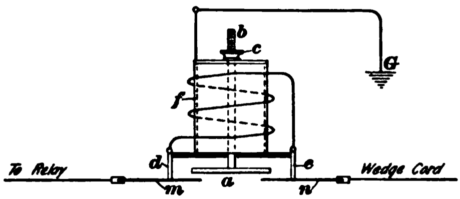


Fig. 10

38. Quadruplex Lightning Arrester.—Fig. 11 shows another form of lightning arrester used to protect quadruplex apparatus. It is known as the **Bunnell quadruplex lightning arrester,** and is used in addition to the ordinary fuse and plate arresters in the line circuit. This arrester is placed directly on the desk with the quadruplex apparatus. The

various parts of the arrester are mounted on a wood or hard-rubber base. To the binding posts *a* and *b* are connected, respectively, the line wire and the wire leading to the quadruplex apparatus. The binding posts stand on plates that have serrated edges close to the grounded plate *e*, thus forming a saw-tooth lightning arrester. These saw-tooth points are supposed to facilitate the passage of lightning discharges to the ground plate. In addition, there is a short coil *c* of insulated wire, wound on a hollow metal cylinder that fits over another metal cylinder joined to or forming one piece with the plate *e*.

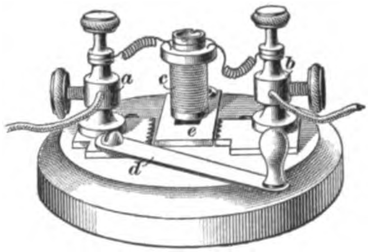


FIG. 11

If a lightning discharge reaches the coil, it may jump across from the serrated edges of the binding-post plate to the ground plate. It may also melt the fine wire with which the coil is wound, and open the circuit. But the chances are that it will also fuse the fine wire to the metal cylinder in its attempt to reach the ground, thus forming an easy or very low-resistance path to earth for the discharge. The fine-wire coil is, of course, destroyed, but the switch *d* may be immediately closed to prevent any serious delay in the telegraph messages passing through the line. The burned-out bobbin, or coil, is replaced by a new one as soon as convenient, new ones being kept on hand for this purpose.

39. Care of Lightning Arresters.—After lightning storms, it is always well to examine the lightning arresters and to repair any damage that may have happened to them. If a lightning arrester that has a thin piece of paper between the ground and the line plates is in use, the paper should be renewed, even if no damage is apparent, for the paper may be invisibly punctured and carbonized at or around such punctures, thus forming more or less of a ground between the plates. With plate arresters, the lightning sometimes not only jumps the air gap, but also goes through the coils. Carbon-block

lightning arresters should be taken apart after lightning storms, especially after severe ones, the carbon blocks cleaned by wiping or blowing away all carbon dust, or by rubbing them on a piece of fine sandpaper laid on a flat surface and blowing off the carbon dust, and carefully put back in proper order. This should be done especially in thinly populated districts where bare line wires are very much exposed.

40. The **ground wire** for lightning arresters should take the shortest and most direct route from the arrester to the ground. It should also have as few bends and turns as possible, as in the case of violent discharges the lightning is very apt to take short cuts through combustible materials and thereby do considerable damage. A spiral of wire, called a pig tail, must not be used between the ground side or terminal of an arrester and the ground. Iron wires will conduct lightning as well as copper wires and it is immaterial whether or not the connection of the ground wires is soldered, provided that no air gaps of great length occur at any of the connections. It is obvious that if lightning will jump over air spaces that a poor joint will offer but little opposition to such a discharge. Nevertheless, it is advisable to make all the joints good and thus offer as good a path as possible to the ground.

FUSES

PURPOSE AND DESCRIPTION

41. Lightning arresters protect apparatus by temporarily or permanently grounding the line wire; and in the case of a lightning discharge, which persists for only a brief time, no other protection is necessary. However, a high-potential current due to a cross between telegraph and high-potential line wires is apt to persist after the telegraph line is grounded at the lightning arrester, and thus cause a very large current to flow over the conductor so grounded, which is very apt to damage the conductor, especially if it is in a cable. It is, therefore, desirable to provide means for opening the circuit

after it has been grounded in case a dangerously large current is produced. This is accomplished, in a simple manner, by the use of a *fuse wire* of limited carrying capacity. The fuse is sometimes called the ***strong-current protector***, because it protects the conductors against relatively large currents, that is, currents of 1 or more amperes. If it were not for the fuse, the arc produced in the lightning arrester, due to a cross with a high-potential wire, might persist and destroy the arrester and perhaps all other apparatus there located and even set fire to the building. The fuse should, therefore, be placed between the lightning arrester and the open line wire where the cross may occur; it should not be placed between the lightning arrester and the instrument or cable conductor that it is used to protect. Fuses are also depended on to open the circuit when the current for any reason exceeds a certain strength. This may be due to a short circuit somewhere or to leakage from other circuits when the potential is not high enough to discharge across the lightning arrester.

42. Fuses are pieces of soft wire that melt and open the line circuit, if the current exceeds a certain value. The capacity of a fuse depends on its location and the line or apparatus it is used to protect. In order to reduce expenses of maintenance to a minimum, the fuse at the office should be of smaller capacity than that in cable boxes outside the office. The office fuse, which is the easier replaced, will usually then blow first and probably prevent the blowing of any other fuse. The larger the current above the limiting value or capacity of the fuse, the quicker it will melt. When a simple fuse melts, it merely opens the line circuit and does not usually ground it; consequently, a fuse cannot be considered as a protection against lightning though it is a fairly satisfactory protection against crosses.

43. Enclosed fuses are now used extensively by both telegraph and telephone companies on all switchboard and outdoor work to protect the wires in cables and apparatus from excessive currents caused by crosses on open overhead wires. They are usually mounted on porcelain bases. The

fuse shown in Fig. 12 consists of an enameled wood, paper, or fiber tube, about $4\frac{5}{8}$ inches long and $\frac{1}{2}$ inch in diameter, with metal terminals secured to the ends. The fuse extends along the center of the hollow tube and has one end soldered to each terminal. The tube, although it may have a small hole to prevent an explosion caused by the sudden heating of the contained air, prevents the scattering of the fuse when it melts, and being almost air-tight protects the fuse from currents of air and thus causes it to operate more uniformly. Sometimes the tube is also filled around the fuse with a non-combustible substance, like gypsum. The tube then contains less air and is less liable to explode.

The fuse is made long so that at least 2,000 bolts across its terminals will be required before an arc can be maintained

Fig. 12

between them at or after the melting of the fuse. For protecting line circuits, the Postal Telegraph-Cable Company uses either 10- or 20-ampere enclosed fuses mounted on porcelain bases.

The American Electric Fuse Company makes a long tube of tough unglazed porcelain with three longitudinal holes through it. The fuse is passed through one hole, back through the second hole, and again back through the third hole, the two fuse ends being exposed at opposite ends of the porcelain tube. On each end of the porcelain tube is permanently fastened a ring to which the fuse ends can be soldered. To the rings are screwed the terminal ends, called *heads*, which may be unscrewed at any time to inspect or renew the fuse wire. The long fuse is said to make it very reliable and safe and the little gas or heated air produced can escape through the unglazed porous porcelain.

44. A protecting device largely used at one time by telegraph companies consists, as shown in Fig. 13, of a small block

between the terminals of which is a very fine fuse or German silver wire about 1 to 1½ inches long. In order to prevent the breaking of the fine fuse wire, it is usually mounted on a thin fiber, or mica, strip, on the ends of which are fastened, by rivets or otherwise, thin metal terminals. The fine wire is soldered

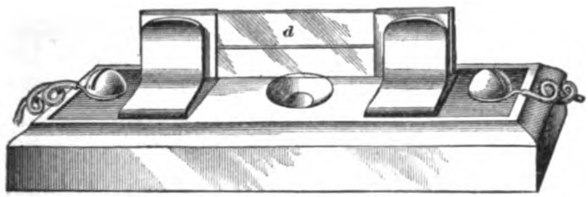


FIG. 13

to the metal terminals, which are generally made of German silver, brass, or copper, and of such a shape that they may be readily slid between the clips or under the screws of the fuse block. The ratings of fuses, especially soft alloy fuses, are not very reliable, and it is not an unusual thing for a fuse to carry a current considerably over its rated capacity. Fine German silver and copper fuses are more reliable than alloy fuses, but such fine wire is required that it is easily broken and hard to fasten properly in place.

45. Western Union Fuse Protector.—The protecting devices used on the main lines of the Western Union Telegraph

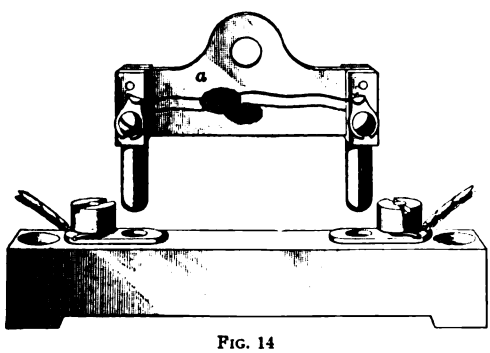


FIG. 14

Company consist of a short piece of No. 20 fuse wire, around one end of which is wound a number of turns of No. 30

silk-covered German silver wire. If the current through the German silver wire becomes abnormally large, the heat developed by the coil and in the fuse wire itself combines to melt the fuse wire and thus open the circuit. It is said to be capable of such accurate adjustment that it will open the circuit on any desired current with great certainty. For the main lines, these protecting devices are adjusted to open the circuits if the current exceeds $\frac{3}{4}$ ampere.

46. In Fig. 14 is shown a fuse of the kind just described, but mounted on a separable fuse holder made of fiber, with round brass end pieces that fit into corresponding holes in the binding-screw terminals. These terminals are mounted on a porcelain base. The fuse holder in this make takes a fuse $1\frac{1}{2}$ inches long. A coil of insulated German silver wire *a* is wrapped about a portion of the fuse and included in the circuit in series with the fuse. When a fuse melts, the fuse holder can be quickly removed and replaced by a good one.

COMBINED STATIC AND FUSIBLE ARRESTERS

47. Postal Fuse and Arrester.—Fig. 15 shows a combined lightning arrester and fusible cut-out used by the Postal Telegraph-Cable Company to protect the lines and apparatus from both high- and low-potential currents. The $\frac{1}{2}$-ampere fuse used for instrument protection is enclosed in a tube with brass terminals that slip tightly into the springs *a* and *b*. The length of the tube enclosing the fuse is $4\frac{5}{8}$ inches and its diameter about $\frac{1}{2}$ inch. The terminals *a* and *b* are fastened to a porcelain base, upon which is also mounted the lightning arrester.

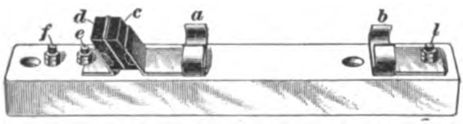


FIG. 15

The latter consists of suitable springs for holding two carbon blocks *c* and *d* that are separated from each other by a sheet of mica, varying from 10 to 100 mils in thickness, depending on where the arrester is to be placed in the circuit. One carbon

block *c* is in contact with a terminal *a* and the other *d* is in contact with a terminal *e* that should be connected to ground. The terminal *f* is connected under the block to the spring clip *a* and insulated carefully from the ground terminal *e*. The overhead-line side of the circuit is connected to binding post *l* and the office-instrument, or cable side, of the circuit is connected to the binding post *f*. A current of sufficient strength will melt the fuse and thus open the circuit. If the voltage is sufficiently high, the charge will jump from the carbon *c* across the gap containing the mica, which is usually perforated or **U**-shaped, to the carbon *d* and pass to ground. If the high voltage persists long enough to form an arc across the carbons, the fuse will melt and thus open the circuit. The high voltage ordinarily used on light and power circuits cannot maintain an arc from one terminal of the fuse to the other, on account of their great separation. The carbon blocks can be readily slipped out and cleaned and returned to their places, or new ones substituted. The long enclosed fuses are also mounted on similar porcelain bases without the lightning arrester for use where a fuse but no arrester is required.

48. Western Union Fusible Cut-Out and Arrester. In Fig. 16 is shown the fusible cut-out and lightning arrester used by the Western Union Telegraph Company. The fuse is enclosed in a wood or fiber tube *a* filled with powdered asbestos or gypsum and provided with brass caps so that it may be readily removed or pressed into place in clips *b* that are stamped out of one piece of brass. Each clip *b* is secured to a porcelain, or slate, base *c* by a machine screw, nut, and washer. Where a wire chief is present, .8-ampere fuses are used, but more often the fuses have a capacity of 2 or 3 amperes, and in isolated places as high as 10 amperes, though 5 amperes is the rule for outside cable boxes.

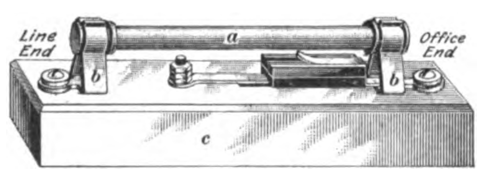


FIG. 16

The arrester consists of two small carbon blocks separated by a piece of mica having in it three small holes through which discharges can readily pass. The arrester is located under the fuse so that the latter must be removed before the carbons can be taken out. This makes a very compact arrangement and compels the opening of the line circuit before the carbons can be touched, thereby reducing the liability of a shock due to a cross with a power or light circuit. The arresters are made in both the single- and the double-pole type; that is, with one fuse and arrester or with two fuses and two arresters mounted on one porcelain or slate base.

CHOKE-COIL PROTECTORS

49. Type D Argus Arrester.—One type of Argus arrester is shown in Fig. 17. It contains a hollow porcelain cylinder tapered from the center toward each end and in a spiral groove is wound the bare copper wire *w*. This is enclosed in but separated by a suitable air gap from a corrugated copper casing *c*, which is connected to the ground. The sparking distance between the convolutions of the copper wire and the inside surface of the corrugated cylinder gradually increases from the center where the air gap is about $\frac{1}{32}$ inch toward each end where the gap is about $\frac{1}{8}$ inch. A lightning discharge is supposed to be broken into a number of discharges from the various convolutions of the spiral to the grounded corrugated cylinder. The spiral has very little resistance for a direct current, but offers considerable opposition to an oscillatory lightning

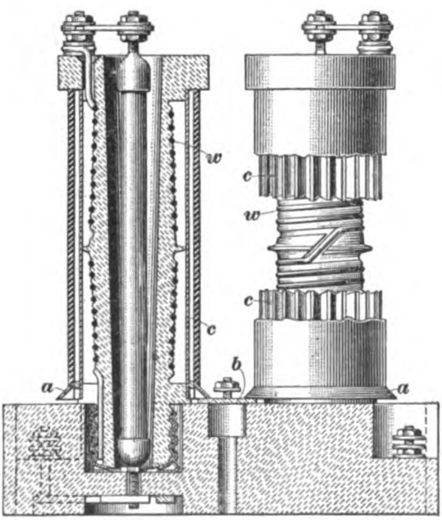


FIG. 17

discharge. Furthermore, this opposition increases the nearer to the center that the lightning discharge is able to penetrate, but as the air gap decreases in length its opposition to the discharge to ground decreases. Consequently, the opposition toward the center increases with each turn, while that to the ground decreases. It is claimed that lightning discharge can be dissipated and broken up better from the sharp edges such as this arrester possesses, than from flat surfaces.

On account of the double taper, it makes no difference which end is connected toward the line, and it is suitable for use in lines at way stations where storms may approach from either direction. Each discharge is claimed to be generally so small as to be harmless, and at no one point is there a discharge of sufficient intensity to produce a burr, as frequently occurs on simple metal-plate arresters. Burrs on metal-plate arresters frequently allow the direct current to form an arc and then produce a permanent ground that must be removed by filing. The Argus lightning arrester is said to remain in condition to protect the circuit at all times from lightning and requires little or no attention. Furthermore, the arrester has a hollow center in which an enclosed fuse is placed to protect the telegraph circuits against crosses with high-tension circuits. The corrugated copper casing has a wide flange *a* at the bottom that makes contact, when placed in position, with a strip *b* that should be connected to the ground. The porcelain base has projections and depressions that interlock one with the other, so that as many as thirty arresters can be placed in a space 1 foot square.

50. Sumpter Multi-Discharge Arrester.—In Fig. 18 is shown the combined fuse and multi-discharge arrester made by the Sumpter Telephone Manufacturing Company. The distinguishing feature of this protector is the square-shaped choke coils *a* made of square wire. The coils were made in this manner because lightning objects to going around coils and sharp corners that possess inductance. In the depression in which these square choke coils are placed is a ground plate insulated from the choke coils by mica. The gap between

the ground plate and the choke coils is adjustable to permit any anticipated voltage to jump it. The cover *b* of the arrester is carbon faced and insulated from the coils by mica and forms another ground plate. The arrangement is such that the coils not only tend to choke back or prevent lightning charges from flowing through them on account of their inductance, but it is claimed that the ground plates being adjacent to the sharp bends and the sharp corners of the square-wire coil, favor the escape of the lightning as it tends to depart from the coils.

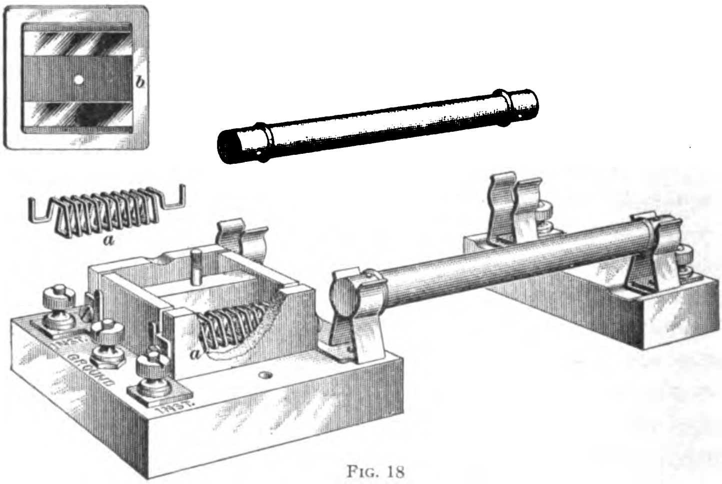


Fig. 18

The choke coils are completely enclosed in the porcelain base, but are readily removable with a screwdriver should they become damaged, which is said by the makers to rarely happen.

51. Connected in series with each choke coil is a tubular fuse provided with spring clips, so that the tubular fuses may be readily removed and replaced without the use of tools. The lines should be connected to the fuse so that if the line becomes crossed with a high-voltage wire, the fuses will open the circuit before an arc can persist long enough between the ground plate and the coil to destroy or damage the arrester. The tinned-iron wire choke coils have a resistance of only a fraction of an ohm and offer no appreciable impedance to telegraph or telephone currents.

SNEAK-CURRENT PROTECTORS

52. Sneak currents may be caused by the telegraph line coming in contact with a low-potential line, such as an incandescent-light or another telegraph line, or with a high-potential line through a high resistance. Another cause of sneak currents is due to the grounding of the telegraph wire or the crossing of two telegraph wires, in which cases the current produced by the battery may be sufficient to cause ultimate damage to the apparatus.

Protection against such currents is usually obtained in telegraph offices by the use of fuse wire, but with the small fuses sometimes required for this purpose, currents of a certain strength cannot always be depended on to melt the fuses and open the circuits. On account of their small size, such fuses are, moreover, very frail and subject to mechanical injury. The device variously called a **heat coil**, or a **sneak-current, protector** will, however, afford this protection.

53. American Heat Coil.—An inexpensive heat coil made by the American Electric Fuse Company is shown at *a*, Fig. 19. It is made of insulated wire wound upon one end of the hook *b* and held in place within a metal shell bv wax. The wax is normally hard, but becomes soft when the coil is heated. A strong spring *c* pulls the wire *b* out of the coil *a* and breaks the circuit between the terminals *e* and *f* when the wax is softened by a current, somewhat larger than normal, passing through the coil *a*. The holder shown is made for insertion in regular Western Union fuse blocks, like the one shown in Fig. 13. They are also made with suitable terminals for Postal-Telegraph fuse blocks and combined carbon-block lightning arrester, and heat-coil protectors are

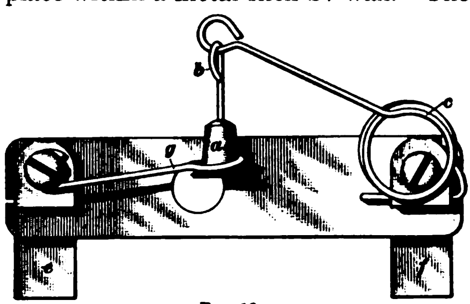


FIG. 19

made with porcelain bases and suitable terminals to which the springs *g* and *c* are directly fastened.

54. Quadruplex Heat-Coil and Lightning Arrester. In Fig. 20 is shown a combination protecting device used in 1907 to protect some quadruplex sets of the C. B. & Q. R. R. Lightning, entering from the line, encounters the inductance

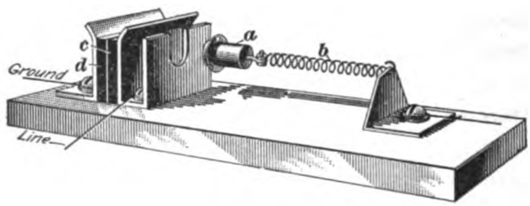


FIG. 20

in the 30-ohm heat coil *a* and in the coiled steel spring *b*, and naturally takes the non-inductive path from one carbon *c* through the small air gap to the other carbon *d* and to ground. The heat coil *a* is shown removed from the slot in which it is normally held so that its shape can be better seen. The carbons are separated by a thin sheet of perforated mica. A small current, called a sneak current, will, if it exceeds a certain value for a given number of seconds, unsolder the plunger in the heat coil *a* and thus allow the steel spring *b* to pull the plunger out of the heat coil and so open the circuit. There is usually a fuse in the line near where it enters the office, thus the quadruplex sets are protected from lightning, sneak currents, and large currents entering from the line.

55. Sterling Heat Coil.—The heat coil made by the Sterling Electric Company and extensively used for protecting telephone apparatus from sneak currents is shown in Fig. 21. The coil of silk-covered German silver, or other high-resistance, wire has one end soldered with ordinary hard solder to one brass

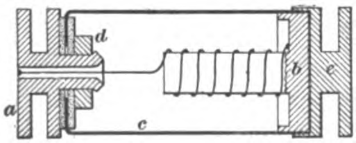


FIG. 21

end piece *a* and the other end is similarly soldered to the brass piece *b* upon which it is wound. A brass shell *c* is fastened to

but insulated from the piece *a* by mica washers and a nut *d* and soldered with hard solder to the piece *b*. The end piece *e* fits easily over the shell and against *b*, to which it is held by a special soft solder made of about 1 part of tin, 1 of cadium, 2 of lead, and 4 of bismuth, and which melts at about 160° F. The end pieces *a* and *e* are designed to slip into flat springs that tend to pull them apart. When the current through the resistance coil is sufficiently strong, say .3 ampere, and lasts long enough, say 25 seconds, the heat produced is sufficient to soften the soft solder between pieces *b* and *e*, thus allowing the springs to pull *e* away from *b*, thereby opening the circuit. The same coil would carry .15 ampere for 5 minutes without operating and the usual telephone current for an indefinite length of time. In fact, heat coils can be designed to open the circuit when any desired current flows for almost any desired length of time. For telephone circuits, the coil is usually wound non-inductively.

56. Sterling Combined Protector.—In Fig. 22 is shown a combined heat coil and static arrester made especially for protecting telephone instruments from lightning and sneak currents. It is double-pole, that is, it protects the apparatus from dangerous currents entering over either line wire. One line wire is connected to binding post *A*, the other to *C*. From the post *B*, and another not shown wires run to the apparatus to be protected, while *E*, which forms a part of the piece *e*, is connected to ground. When the heat coil operates, the piece *f* flies against the piece *e*, thereby opening the circuit

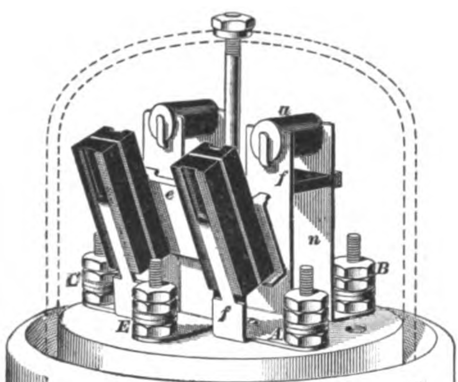


FIG. 22

between *f* and *n* and grounding the line wire coming to post *A*. The carbon blocks protect the apparatus from lightning or static discharges when the electromotive force exceeds 350 to 400 volts. The carbon-block static protector, the long enclosed fuse, and the heat coil are extensively used to protect telegraph and telephone circuits and apparatus. They are made and grouped together in many ways but their principles of operation are about the same as those that have been here explained.

TELEGRAPHY

(PART 2)

TELEGRAPH SWITCHBOARDS

SWITCHBOARDS FOR SMALL OR INTERMEDIATE OFFICES

ORDINARY TYPE OF SWITCH

1. The **plug switch**, a portion of one of which is shown in Fig. 1, is a form much used in telegraph offices. It consists of alternate brass plates P and P_1 and rows of brass buttons or disks B, B_3, etc. This board is erected in a vertical position, and the disks in each horizontal row are connected together. Thus, any one wire on the horizontal side may be connected to any one on the vertical side by inserting a plug or peg M into the proper aperture, as at N. Part of the plug M is of hard rubber and the other part is of brass, and should be slotted to insure elasticity. All the circuits in a large station are appropriately numbered, so that wires *1* and *1*, for instance, as well as *2* and

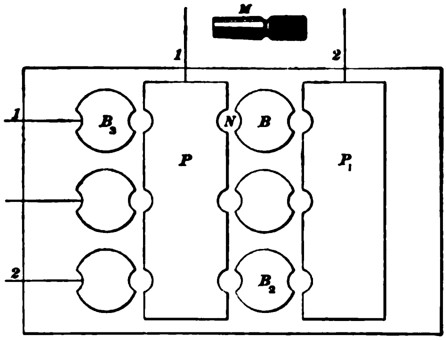


FIG. 1

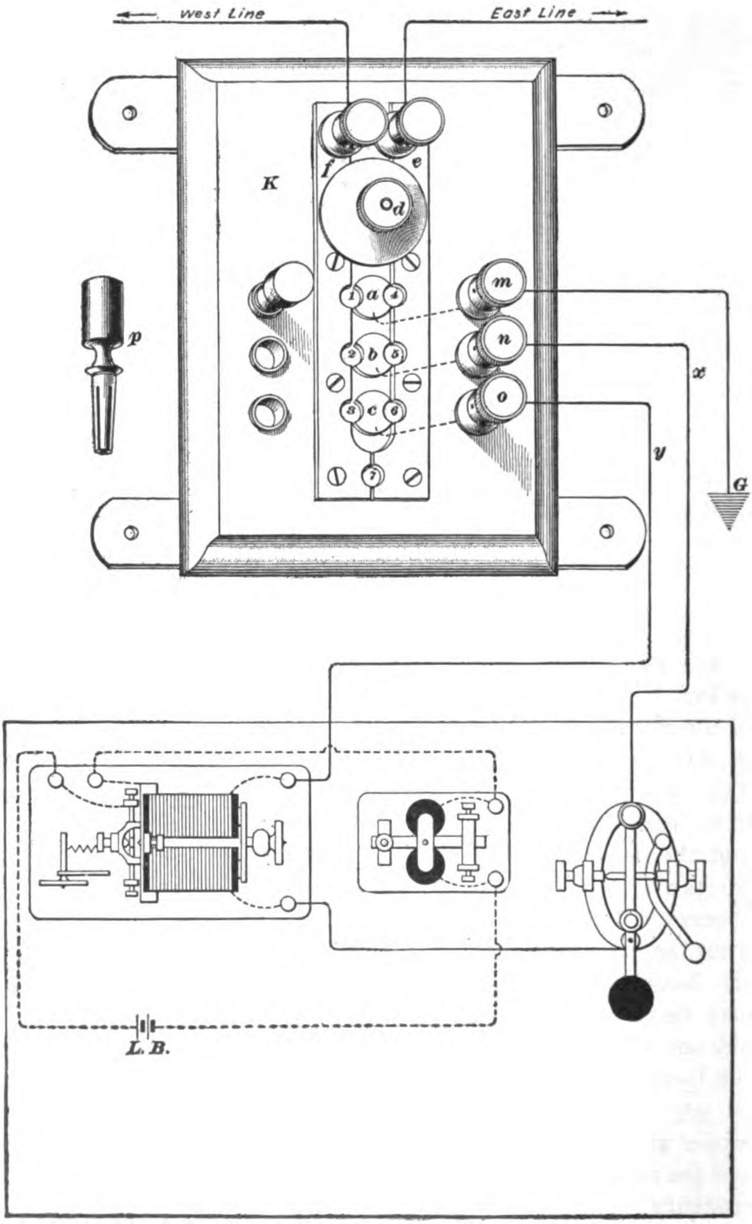


FIG. 2

2, may be connected together by inserting plugs at the junction of B_3 and P, and at the junction of B_2 and P_1, respectively.

In order to insure a good firm connection, the plugs should always be firmly pushed into the holes with a twisting motion. The switches used in a telegraphic circuit should be substantial and all contacts must be good and firm. A loose or faulty connection at any point will often render the adjustment of the springs governing relay armatures, etc. exceedingly difficult and annoying, if not impossible.

PLUG SWITCH FOR ONE MAIN LINE

2. In Fig. 2 is shown the arrangement of apparatus at an intermediate office or way station. The plug switch K enables the necessary changes in connections between the east and west lines, the ground, and the instruments to be easily made. The switch is fastened to the office wall in a vertical position. The two long brass strips e and f, each of which has a binding post fastened to its upper end, are screwed to a thoroughly dry and seasoned wooden baseboard, and are insulated from each other and from all other metal parts of the switch. The east line is fastened to the binding post e and the west line is fastened to the binding post f. The button d has a screw extending through the wooden base into a metal strip that is connected behind the board with the binding post m, and, since this binding post is connected to the ground plate G, then d is also grounded. This button d extends over, but is insulated from, both e and f by a thin sheet of paraffined paper or mica, thus forming a lightning arrester. As indicated by the dotted lines, the small brass pieces, or disks, a, b, and c are connected by wires behind the board to the binding posts m, n, and o, respectively. The disk a, which is connected to the binding post m, is grounded; while b and c, which are connected to the binding posts n and o, respectively, and thus to the key and relay upon the table, form the terminals of these instruments on the switch. There are three plugs p, which may be inserted in any of the holes *1*, *2*, *3*, *4*, *5*, *6*, *7*; when not in use they are kept in the holes on the left side of the board.

3. To Cut Out the Key and Relay.—If a plug is inserted in hole *7*, all the other holes being left open, the east and west lines are connected directly together, and the current can pass from the east to the west line, or vice versa, without passing through the instruments at this intermediate office. When arranged in this manner, the grounded disk *a* and the disks *b* and *c* (the terminals of the office set) are entirely disconnected from the main line. The office or desk set is then said to be cut out. When leaving the office, or during a thunder storm, the switch should be arranged in this way, so that no current can pass through this office relay.

4. To Cut in the Key and Relay.—When the east and west lines are connected together directly by a plug in hole *7*, the key and relay may be cut in without opening the main-line circuit, even for an instant. To do this, insert plugs in holes *3* and *5*, and then remove the plug from hole *7*; all holes except *3* and *5* should be open. Before removing the plug from hole *7*, see that the key is closed. The key and relay are now in series with the main line, and current from the east line, for instance, will pass down the strip *e* through the plug in hole *5*–disk *b*–binding post *n*–key and relay–binding post *o*–disk *c*–plug in hole *3*–strip *f*, and out to the west line.

The key and relay could be cut out by putting plugs in holes *2* and *5* or *3* and *6*, instead of one plug in hole *7*. If the key and relay are cut out by plugs in *3* and *6*, to cut them in, put a plug in hole *2* and then remove the plug from hole *3*; or put a plug in hole *5* and remove the plug from hole *6*. This is the only way to do it in that form of switch in which the strips *e* and *f* are cut off immediately below disk *c* and no connecting hole is provided at *7*.

5. To Ground Either Line.—To ground the west line alone, put a plug in hole *1*, all other plugs being removed. Similarly, to ground the east line, put a plug in hole *4*.

6. Tests for an Open Line.—The following cases of trouble might confuse an operator located at a way station through which only one line wire passes, as shown in Fig. 2, when testing for an opening, say in the west line. The relay

when connected in series with the east and west line wires stands open with both lines open, both lines grounded, one main battery reversed and equal in strength to the main battery at the distant terminal. The proper method to pursue is as follows, each step to be taken in the order given and assuming that the relay and key are in the circuit with the east and west lines:

1. Ground the east line, for instance, by inserting a plug in hole *4*; if this closes the relay it indicates that the line is open east or the battery at the eastern end is reversed. If the relay does not close, the line is open or grounded west.

2. Ground the west line, for instance, by inserting a plug in hole *1*. If this closes the relay, the line is open west or battery reversed west. If the relay closes when ground is put on east or west, there is a reversed battery, which may possibly be due to a cross as well as to a reversed battery at the terminal office.

If the relay does not close when grounded west, it is open east or grounded east. There is no ground east or west if the relay stands open when commencing to test and before any grounds are put on. The condition of reversal has now been eliminated and it remains to prove that both lines are grounded or both open. If the line was open at the office testing, no circuit could be obtained in either direction, and a quick test may be made by touching the terminals with the fingers of one hand or noticing whether a spark is produced when main-line posts are short-circuited; assume this to have been done and that the relay has been proved not to be open, providing there is battery on the line.

Of course there remains the condition of relay open when both lines are grounded and when both lines are open. If such a condition is suspected, at a station like that shown in Fig. 2, current from the local battery should be sent through the relay by wiring the battery to the main posts at the top; if the relay closes on a low adjustment it eliminates that case.

After proving that the relay is all right and is connected properly to the posts at the top of the board, there is no way of proving at a way station whether both lines are open or both

grounded unless another wire is available. A very near ground could be determined by grounding one side of the local battery and connecting the other, through the relay, first to one side and then to the other side of the line. If the ground was close, the relay would close. Therefore, if no circuit can be obtained either way and the home relay is all right when tested as above, all that can be said is, that both lines are open or both grounded.

If the case is a simple one, namely west line open and east line all right, the tests and conclusions are as follows: Ground it west, relays closes; east line is all right. Ground it east, relays remains open; west line is open.

These conclusions are based on the observation that the relay stands open before commencing to test.

7. To Locate an Open Circuit or Cross in Way-Office Circuit.—If it is not certain that the office instruments and circuits are all right, put a plug in hole *7* of the switch, remove all other plugs, and then test the relay, key, and connections for an open circuit somewhere; or, perhaps, there may be a short circuit or cross in the relay coils or in the wiring. An open circuit may be tested for as follows: Disconnect the wires of the local set from the binding posts o and n, and fasten these two wires x, y to the terminals of a battery having sufficient electromotive force to send the regular working current through the relay. For instance, for a 150-ohm relay whose normal working current is 20 milliamperes, the electromotive force of the battery should be about $150 \times .02 = 3$ volts, so that three or even two gravity cells may be sufficient.

The key should then be opened and closed. If the relay is suitably adjusted, no movement of the armature will indicate an open circuit somewhere, or a short circuit or cross in the relay coils, or between the two wires running to the relay. To locate the trouble, close the key, disconnect the wire x from the key, and touch it first to the other terminal of the key. A movement of the relay armature would indicate that the open circuit was in the key. If there is no movement, the battery wires should be applied directly to the relay

terminals. A movement of the armature would indicate that the trouble was in the wiring somewhere external to the relay. No movement would locate the trouble in the relay. In the latter case, the relay should be overhauled and repaired or a new one obtained.

8. One of the quickest ways for an operator at a way station to find out whether the opening in a circuit is in his own instruments or office connections is to insert a knife blade loosely across the cut-out hole *7* at the bottom of the board. If the opening should happen to be in the circuit from the switchboard through the key and relay back to the switchboard, a spark will be seen between the edge of the blade and the brass pieces every time the contact is broken. His relay, of course, will not close, but the circuit will be all right to all the others on the line, so long as the knife makes a good connection. Some prefer to feel for the current at each of the top binding posts, but, as the sensation, if the lines are all right, is not always very pleasant, the knife process is not only just as satisfactory, but it is frequently more certain, for the reason that a spark will appear on breaking a circuit, although the current may be too weak to be felt with the fingers.

When feeling for a current, it is dangerous to use both hands. Two fingers of one hand may be placed across the points to be tested and the other hand kept in the pocket or somewhere else where it cannot touch the circuit or a ground. If this precaution is observed, and should the fingers be placed across a circuit whose potential is dangerously high, the sensation may be disagreeable and the fingers burned, but if both hands had been used, the current would have had a good opportunity to flow through some of the vital organs, especially the heart, with perhaps more or less serious results.

PLUG SWITCH FOR TWO THROUGH LINES

9. When two or more through main lines pass through a way office, a switch whereby various combinations may be made between these wires and the office instruments is very desirable and even necessary. A convenient form of switch for two

main lines and two office sets is shown in Fig. 3. The binding post *u* is connected to the disks *a* and *b* by wires behind the base-board; similarly, *v* is connected to *c* and *d*, *w* to *l* and *i*, and *x* to *m* and *n*. The post *h* is connected to the plate *g*, which, being separated and insulated from the vertical strips by a thin piece of mica or paraffined paper, forms the ground plate of a lightning arrester. Any vertical strip and the line wire connected to it may be grounded by inserting a plug in the proper hole in the top horizontal row. Two sets of instruments located in the way office and the two through main lines,

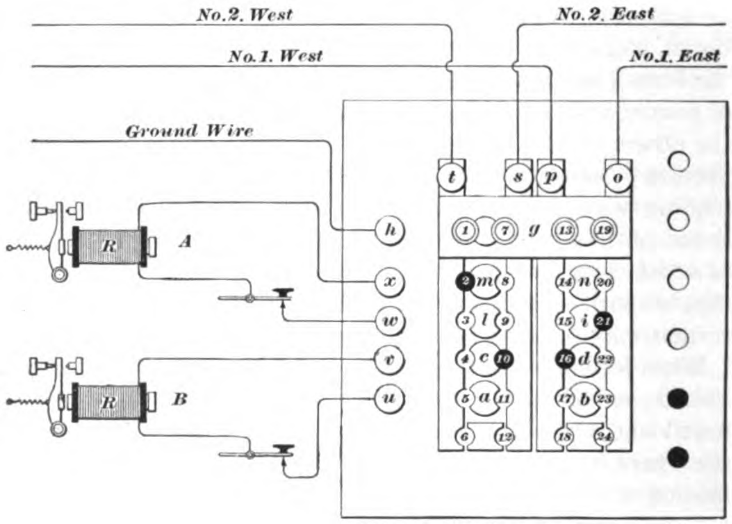


FIG. 3

ordinarily called No. *1* and No. *2* lines, are connected to binding posts on the switch, as shown.

10. Instruments Cut Into Both Line Circuits.—To loop the set *A* in line No. *1*, that is, to connect the set *A* in series with the line wires No. *1* east and No. *1* west, and also to connect the set *B* in series with the wires No. *2* east and No. *2* west, insert plugs in holes *21*, *14*, *11*, and *4* or in holes *20*, *15*, *10*, and *5*. Similar connections, whereby one office set was cut into a line circuit, have already been explained, so no explanation seems necessary here.

11. Cross-Connections.—To cross-connect the line wire No. *1* east to No. *2* west, and No. *2* east to No. *1* west, with or without an office set in each circuit is easily done. Plugs are shown in holes *21* and *2* in order to connect line wire No. *1* east and No. *2* west with the office set *A* cut in, and in holes *10* and *16* in order to connect line wire No. *2* east to No. *1* west without an office set. The set *A* may be cut out by simply shifting the plug from hole *21* to *20*, and set *B* may be cut into circuit with line wires No. *2* east and No. *1* west by shifting the plug from hole *16* to *17*.

12. Looping.—Joining together two east-line or two west-line wires is called **looping**, and an office set may or may not be included in the loop. For instance, if it is desirable to connect the set *A* in the loop between line wires No. *1* east and No. *2* east, insert plugs in holes *20* and *9*. If No. *1* west and No. *2* west are to be looped directly together without an office set, insert plugs in holes *16* and *4*. Other combinations may easily be made between the various line wires and the office sets, but the foregoing sufficiently illustrates the manner of using this form of switch.

PLUG SWITCH FOR MORE THAN TWO LINES

13. The plug switch described for two main lines that enter a way station may be extended almost indefinitely. In Fig. 4 is shown a plug switch for four pair of line wires that are brought to the binding posts at the top of the switch. Just below the line-wire binding posts are the circular lightning-arrester plates or buttons. These buttons are all connected through a horizontal brass strip behind the board to the top binding post *m*, which is connected to a ground plate *G*. To the binding posts at the right side, excepting the top one, are connected the office sets. Each one of the side binding posts is connected behind the board with all the circular disks in the same horizontal line with it.

14. Split Plug and Its Use.—A very convenient device by means of which an extra office set may be connected in series with a line and another office set, or *looped in*, as it is

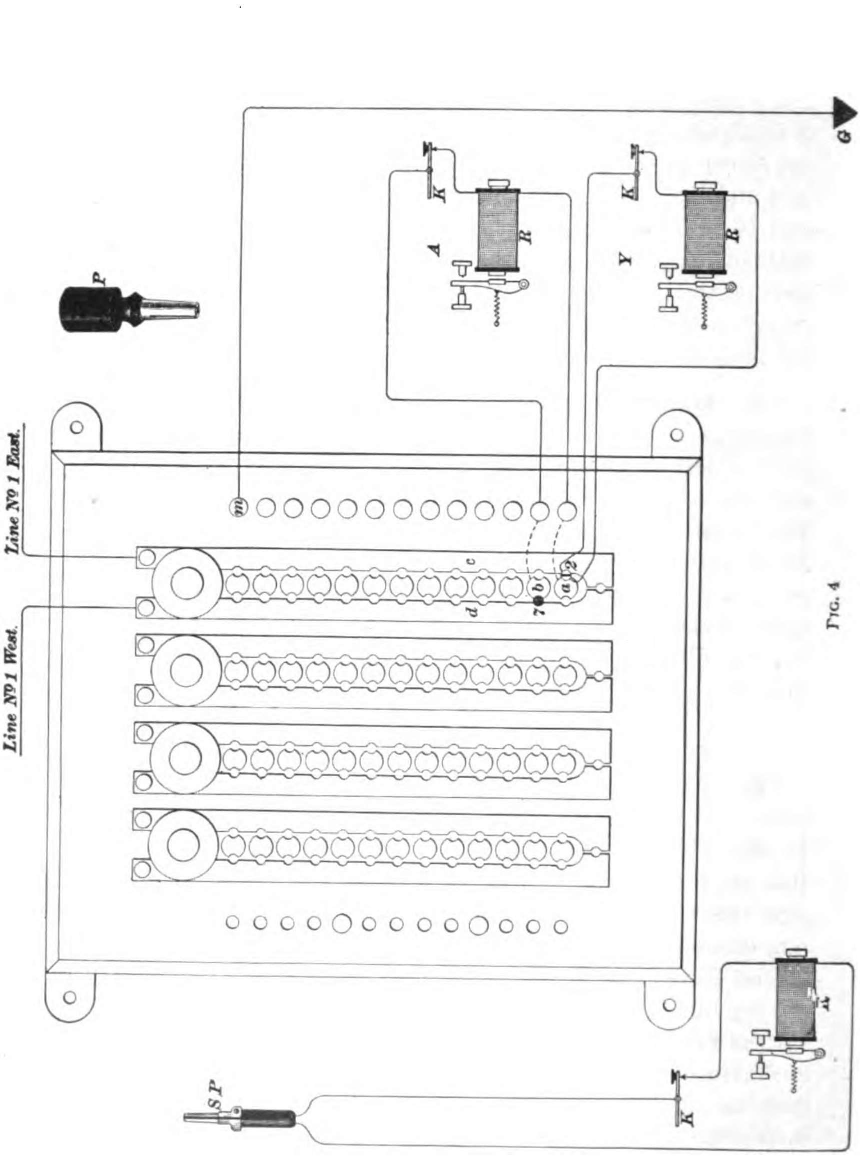


FIG. 4

commonly called, is the split plug SP. The plug consists of two brass strips, insulated from each other by a center strip of hard rubber and a handle of the same material. To the brass strips are connected the two wires running to an office set, as shown. For instance, suppose it is desired to connect in series with the

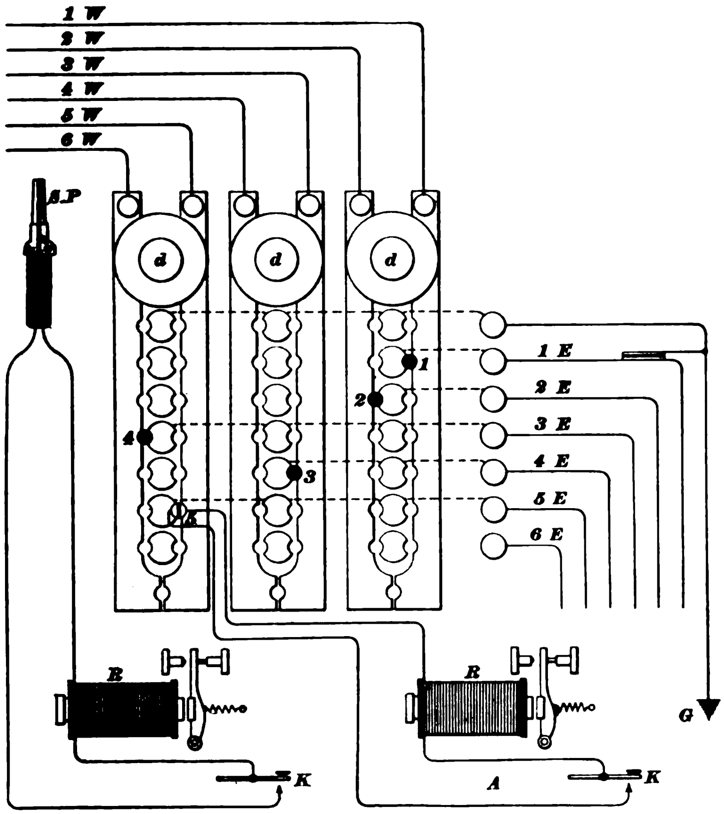


FIG. 5

No. *1* line and the office set A another set Y. An ordinary plug P is put in hole *7* and a split plug SP in hole *2*, being careful when this split plug is in place that the same brass piece on one side of the plug does not touch both the disk a and the vertical strip c of the switch. When the plugs have been properly inserted in the holes indicated, the circuit is as

follows: From line No. *1* east through the vertical strip *c* – one side of split plug–set *Y* – other side of same split plug – disk *a* – office set *A* – disk *b* – ordinary plug in hole *7* – vertical strip *d* – line No. *1* west. In this manner, an extra set can be looped in with any of the regular office sets.

15. The capacity of a given switch of this form may be doubled by bringing the east wires, for instance, to the binding posts on the right side of the switch, reserving the top binding posts for the west wires. When arranged in this way, all the office sets must end in split plugs. In Fig. 5 is shown a portion of a switch and two office sets arranged in this manner. If ordinary pin plugs are placed in holes *1*, *2*, *3*, and *4*, the following wires are connected through the switch without any office sets in circuit with them: No. *1* east to No. *1* west, No. *2* east to No. *2* west, No. *3* east to No. *6* west, No. *4* east to No. *3* west. If a split plug is properly inserted in hole *5*, the office set *A* is looped in between No. *5* east and No. *5* west.

An objection to this arrangement is that the office instruments connected in circuit with the line wires are not protected by the regular lightning arresters *d* at the top of the switch from lightning discharges that may come in over the east lines. However, a simple plate or button arrester can be connected to each east line before it reaches the switchboard. A plate arrester is shown connected in this manner to line No. *1* east; the heavy black line between the line and grounded plates represents the intervening insulation, mica, or paraffined paper. In order to loop an office set in circuit with two west wires, without rendering useless one east wire, there must be one or more extra rows of disks that do not connect with any line wires, and furthermore, an office set cannot be looped in circuit with two east wires, even with the extra rows of disks, without rendering useless one west wire.

EXAMPLES OF CONNECTIONS

16. About all the connections that an operator at a small way station will be called upon to make can be shown by the following examples, every one of which should be clearly

understood. Draw simple sketches and blacken the holes, or state the numbers of the holes, as they are given in Fig. 6,

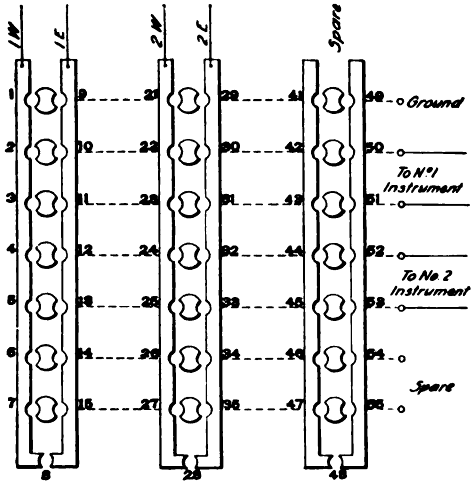


Fig. 6

where plugs should be inserted in order to make the patches specified in the following examples. Usually the desired result

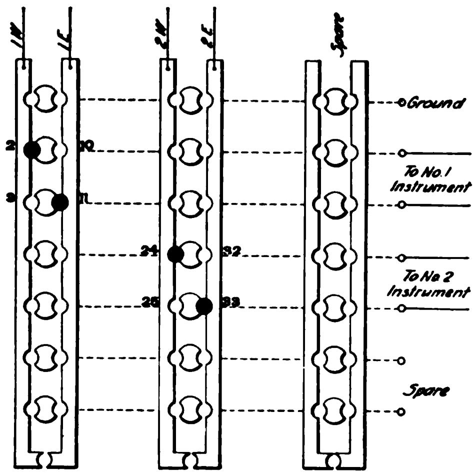


Fig. 7

can be secured in a number of ways, as will be shown in some of the solutions.

EXAMPLE 1.—Connect No. 1 instrument on No. 1 wire and No. 2 instrument on No. 2 wire.

SOLUTION.—Insert plugs in holes *2*, *11*, *24*, and *33*, as indicated in Fig. 7; or in holes *10*, *3*, *32*, and *25*.

EXAMPLE 2.—Connect both instruments on No. 1 wire.

SOLUTION.—Insert plugs in holes *10*, *43*, *44*, and *5*, as shown in Fig. 8; or in holes *2*, *51*, *52*, *13*; or in holes *11*, *42*, *45*, and *4*; or in holes *3*, *42*, *45*, and *12*.

EXAMPLE 3.—(*a*) Connect No. 1 instrument on No. 2 wire with No. 2 grounded east. (*b*) Connect No. 2 instrument on No. 1 wire.

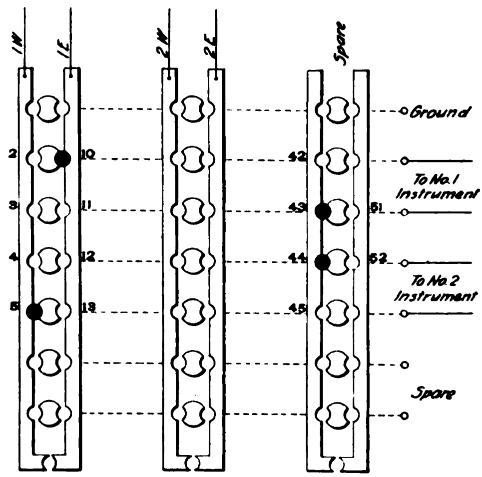


FIG. 8

SOLUTION.—(*a*) Insert plugs in holes *22*, *31*, and *29*, as indicated in Fig. 9; or in holes *23*, *30*, and *29*. (*b*) Insert plugs in holes *5* and *12*, or in holes *4* and *13*.

EXAMPLE 4.—Cut out wire No. 1 with instrument pins and cut out wire No. 2 at the bottom.

SOLUTION.—Insert plugs in holes *2*, *10*, and *28*, or in holes *3*, *11*, and *28*, Fig. 6. The connections should now be clear enough without a separate figure for each solution; if not a separate figure should be drawn for each example with the proper holes blackened.

EXAMPLE 5.—Connect No. 2 east to No. 1 west with No. 1 instrument included, and put a ground on No. 1 east and No. 2 west.

SOLUTION.—Insert plugs in holes *30*, *3*, *9*, *21*, Fig. 6; or in holes *31*, *2*, *9*, and *21*.

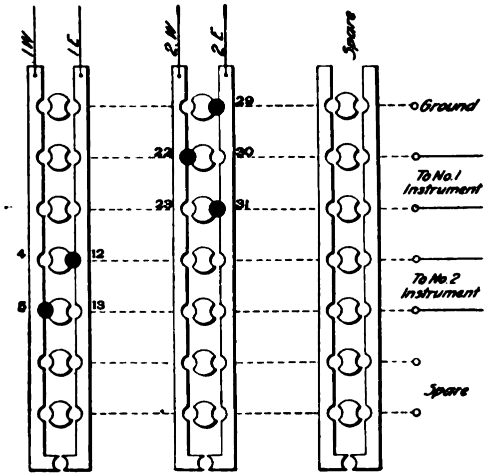


FIG. 9

EXAMPLE 6.—Connect wire No. 2 west to No. 1 east with instrument No. 1; ground wire No. 1 west, and put wire No. 2 east through instrument No. 2 to ground.

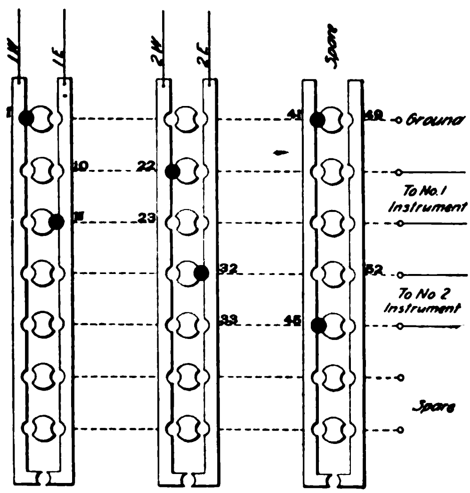


FIG. 10

SOLUTION.—Insert plugs in holes *22*, *11*, *1*, *32*, *45*, *41*, as indicated in Fig. 10; or in holes *10*, *23*, *1*, *33*, *52*, *49*. It also can be done in other slightly different ways.

EXAMPLE 7.—Connect 1 west to 2 west; also 1 east to 2 west with an instrument in each circuit.

SOLUTION.—Insert pegs in holes *2*, *23*, *12*, and *33*, or in holes *3*, *22*, *13*, and *32*, Fig. 6. Plugs in holes *4*, *25*, *10*, and *31* or in holes *5*, *24*, *11*, and *30* will also give the correct connections, because it is not specified with what wires each instrument is to be connected.

SINGLE-LINE SWITCH BLOCK

17. In Fig. 11 are shown the connections for one single-line switch block used by the Postal Telegraph-Cable Company

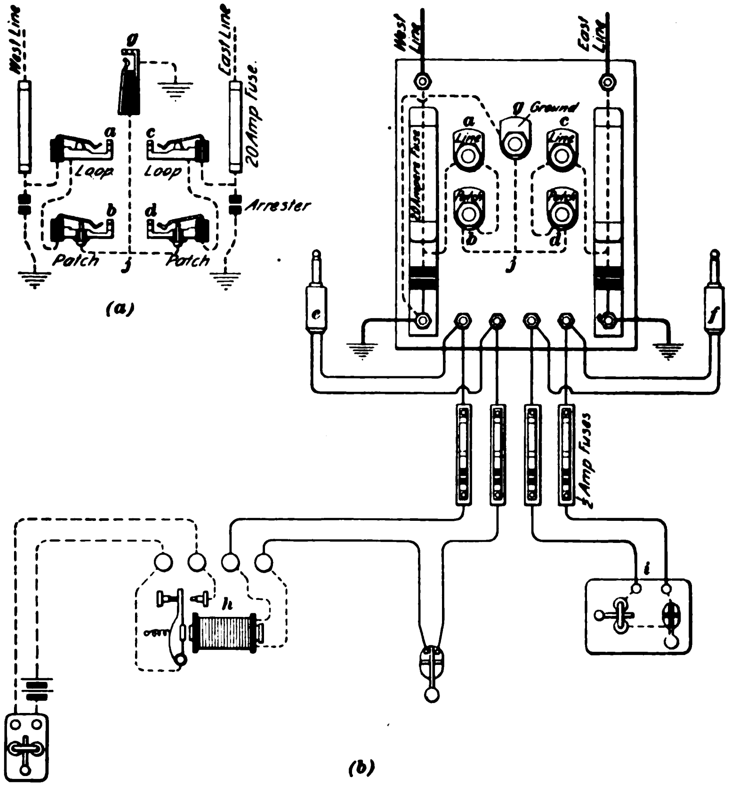


FIG. 11

for main lines. At (*a*) is shown a theoretical diagram of the main-line circuits only, while at (*b*) the general arrangement is

shown better, also the circuits of the local sets. Enclosed fuses, carbon lightning arresters, jacks, and binding posts are mounted upon one porcelain base. There are also fuses and carbon lightning arresters in circuit with the relay and sounder set *h* and in circuit with the main-line sounder set *i*. These sets terminate in double-contact plugs *e* and *f*. A small switchboard may be made by using several of these blocks, patching cords terminating in single-contact plugs being used to make the cross-connections. The jacks *a* and *c* are termed *loop jacks* because a table set may be looped in a line circuit by inserting a double-contact plug *e* or *f* in such a jack. The jacks *b* and *d* are termed *patch jacks*, because two lines not usually connected together may be patched together by inserting the plugs of a patching cord in two such jacks. The loop jacks *a* and *c* keep the circuit closed when there is no plug in them. The ground jack *g* has its grounded side normally open, but the insertion of a metal peg or a single-contact plug in the jack connects the wire *j* to ground and hence grounds both the east and west lines when there are no plugs in the patch jacks *b* and *d*. When there is no plug in any jack the west line is connected straight through to the east line. To open the east line insert a single-contact plug in jack *d* and to ground the west line at the same time insert a single-contact plug in jack *g*.

18. To connect an office set, say set *h*, in series with the west line only, insert plug *e* in jack *a* and a metal peg or single-contact plug in jack *g* in order to keep the east line closed to ground. To work the east and west lines independently, insert plug *e* in jack *a*, plug *f* in jack *c*, and a metal peg or single-contact plug in jack *g*; this assumes that the main-line sounder *i* will receive sufficient current, while looped in the east line, to work it. The patching jacks *b* and *d* normally keep the circuit closed. Suppose there were other similar switch blocks in the same office, and that it was desired to patch the east line shown to another east line, then insert in jack *d* a single-contact plug, which is connected, by a single conductor, to another single-contact plug that is inserted in a corresponding jack on another switch block.

SWITCH BLOCK FOR BRANCH OFFICE

19. In Fig. 12 are shown the connections of a single-line switch block used by the Postal Telegraph-Cable Company for city lines and branch offices where it is not necessary to cross-connect or patch wires. At (*a*) is shown a simple diagram of connections for the switch block only, while at (*b*) the same is shown more in detail together with the connections of the local sets. It is similar to the single-line switch block just

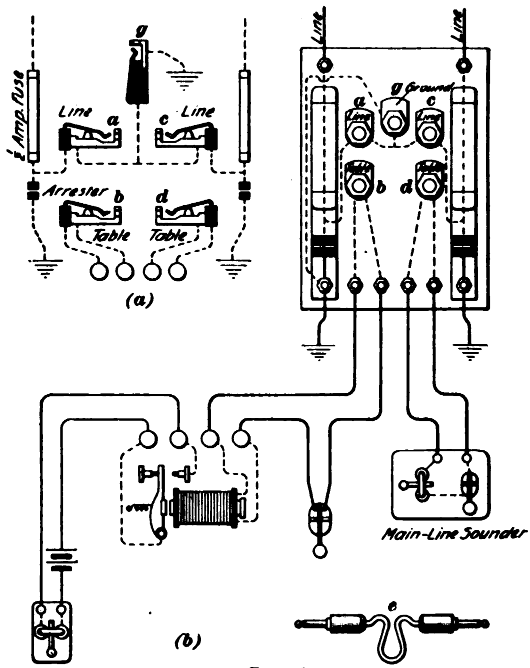


Fig. 12

explained. It has fuses, arresters, jacks, and binding posts mounted on one porcelain base. A relay set is shown terminated at jack *b* and a main-line sounder set at jack *d*. Normally the two line wires are connected together through jacks *a* and *c*. By means of a two-conductor cord *e* terminating in double-contact plugs, either office set may be connected from jack *b* or *d* through jack *a* or *c* to the line. Thus either or both

sets may be connected in the loop from the main office to this branch office. Furthermore, the loop may be made into two lines with ground return for both, that is split, by inserting a metal peg in the ground jack *g*, thereby grounding both line wires. By connecting one office set to jack *a* and the other to jack *c*, two working lines are available; they may also be used as the sending and receiving legs of a duplex or quadruplex set. Several of these switch blocks may be used together where only cut-out devices and no switching facilities are required.

CROSS-BAR SWITCHBOARD

20. The cross-bar switchboard used by the Postal Telegraph-Cable Company in small intermediate offices is shown in Fig. 13. The line wires first pass through fuses and lightning arresters. Each arrester consists of two carbon blocks separated by a sheet of mica 100 mils thick, one block being in contact with a grounded strip and the other in contact with the line circuit. Each east line is connected to one of the vertical metal bars that are behind and insulated from the front horizontal metal bars. Each west line is connected to one of the horizontal bars. One vertical and one

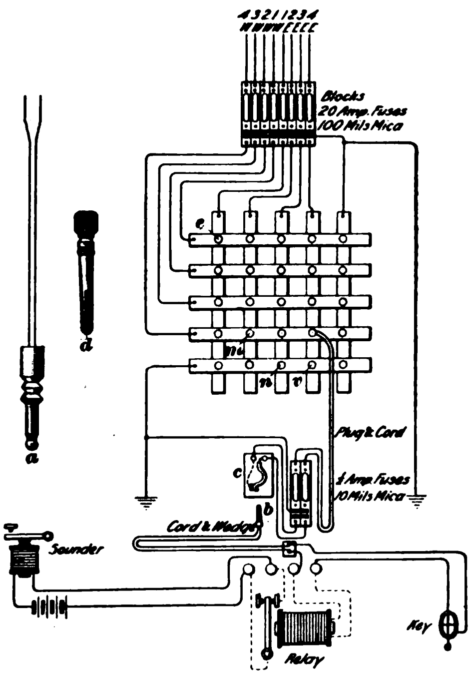


FIG. 13

horizontal bar are connected to ground as indicated. Below the switchboard are mounted, for each operator's set, one spring jack

and a double arrester and fuse block, to the upper terminals of which is connected a flexible cord containing two insulated conductors, the other ends of which terminate in a double contact plug, like the one shown at *a*, which has a metal tip and a metal sleeve insulated from each other. There are holes opposite each other in the vertical and horizontal bars on the switchboard so that when a double contact plug is inserted in a hole as far as it will go, one upper terminal of the protector is connected through the flexible cord to the vertical bar and the other upper terminal of the protector to the horizontal bar. The protector may thus be connected between any one east and any one west line by inserting the double-contact plug in the hole that intersects the two corresponding vertical and horizontal bars. Each relay-key set is connected to a flexible two-conductor cord terminating in a double-contact wedge *b* that can be inserted in the wedge spring jack *c*. Thus, any table set may be connected through an arrester having a sheet of mica 10 mils thick between the carbons and a $\frac{1}{2}$-ampere fuse in series with any east and west line and its protector.

21. To connect any east line directly to any west line, insert a double-contact plug in the hole intersecting the corresponding vertical and horizontal bars. The circuit is then closed through the flexible cord, protector, and spring jack in which there would be no instrument wedge. A better way to accomplish the same object is to insert a single-contact plug, like *d*, in the proper hole; the circuit is then closed from the vertical bar through the plug to the horizontal bar.

To ground any east line, insert the single-contact plug *d* in the proper hole in the bottom horizontal row; to ground any west line, insert the plug in the proper hole in the right-hand vertical row. To connect an operator's set between an east line and ground, insert the instrument wedge in a spring jack and the double-contact plug connected through the protector to the same jack in the proper hole in the bottom row. To connect an operator's set between a west line and ground, insert instrument wedge in a spring jack and corresponding double-contact plug in proper hole in right-hand vertical row.

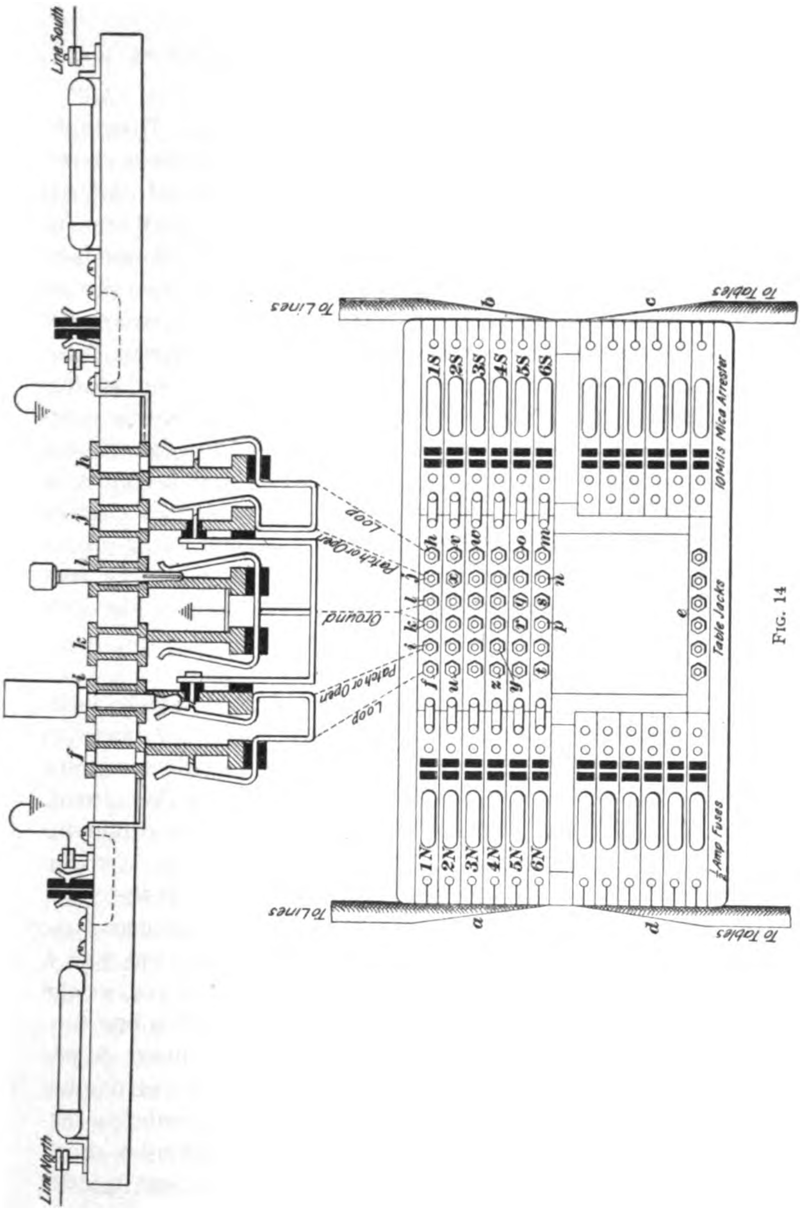

Line South
Line North
To Lines
To Lines
To Tables
To Tables
Loop
Patch or Open
Ground
Patch or Open
Loop
1S
2S
3S
4S
5S
6S
1N
2N
3N
4N
5N
6N
10 Mills Mica Arrester
Table Jacks
½ Amp Fuses

FIG. 14

SMALL JACK SWITCHBOARD

22. A small switchboard used by the Postal Telegraph-Cable Company for offices having not over six lines is shown in Fig. 14. On each side of the center are mounted enclosed fuses and carbon lightning arresters. The six southern (or western) lines are connected to six fuses, and the six northern (or eastern) lines to six fuses. These line fuses in the rows *a b* have a capacity of 20 amperes and the micas between the carbon blocks have a thickness of 100 mils. Six spring jacks are mounted in a horizontal row between each pair of line protectors; a horizontal view through one row of spring jacks and protectors is shown in the upper part of the figure. Six table sets are connected through the fuses and arresters in rows *c* and *d* to the table jacks *e*. Any table set may be looped in any through line by inserting one plug in the proper table jack and the other plug, which is connected to the first plug, by a flexible two-conductor cord, in any one of the loop jacks in the same vertical row with *f* or *h*.

23. To make a patch, insert single-conductor plugs in jacks *i* and *j* in different rows. For instance, to patch *1* north to *6* south, insert plugs, connected together by a single-conductor cord, in jacks *i* and *n*; to include an office set in this circuit, insert plugs that are connected together by a double-conductor cord, one in a table jack and the other in jack *f* or *m*. To open a northern line, insert an ordinary switchboard peg in the corresponding jack in the vertical row *i*; to open a southern line, insert a peg in the corresponding jack in the vertical row *j*. To ground a through line at this office, insert a peg in the proper jack in the vertical row *k* or *l*. To ground a line running in one direction only, for instance north, insert a peg in the proper jack in the vertical row *k* and also a peg or plug in the corresponding jack in the vertical row *j* in order to disconnect the south line from the ground. To ground a south line and open the corresponding north line, insert pegs in jacks *i* and *l* in the same horizontal row. When loop circuits come to this switchboard they pass through line arresters and fuses.

JACK SWITCHBOARD

24. In Fig. 15 is shown a switchboard for intermediate offices having six or more lines. The line wires are brought through cables *a* and *b* to protectors mounted on the front of the board at *e* and *f*. These protectors consist of 20-ampere enclosed fuses and lightning arresters having carbon blocks separated by mica 100 mils in thickness. The arrester side of each protector is connected to a series of three jacks on each side of the center of the board. The first row of jacks on the extreme left and right are looping jacks, the next row of jacks on each side are opening or patching jacks, and the two center rows are grounding jacks. These jacks are connected in exactly the same manner as shown in the preceding figure. Wires from the table sets enter through

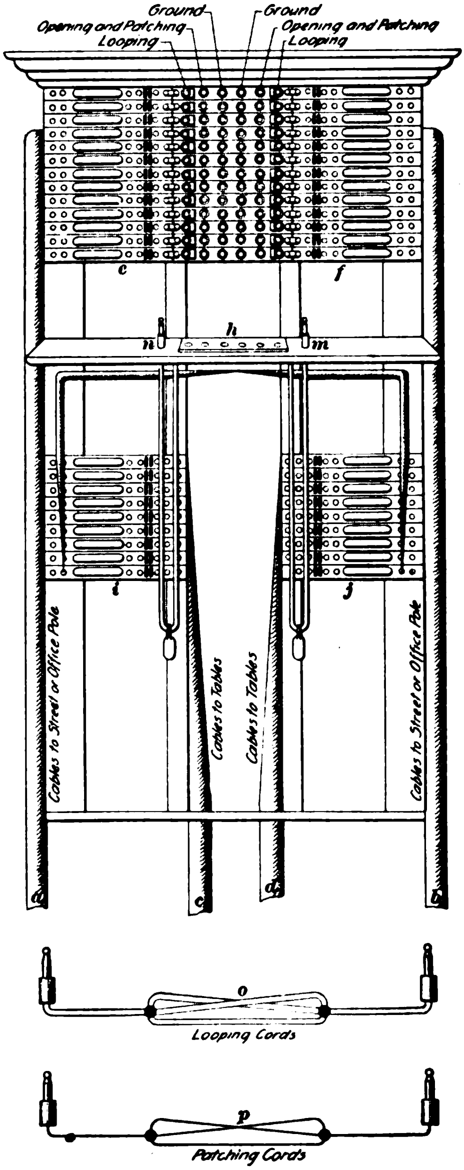


FIG. 15

cables *c* and *d*, pass through arresters, having carbon blocks separated by mica 10 mils thick, and ½-ampere fuses mounted at *i* and *j* to table jacks *h* mounted on the shelf of the switchboard. There are approximately as many table jacks as there are pairs of table wires running to table sets. A couple of testing sets are connected through double-conductor flexible cords, that are kept taut by weights hanging on them under the shelf, to plugs *m* and *n* that rest on the shelf, for insertion in the looping jack of any circuit that needs attention. Loops are connected through line fuses and arresters to jacks and they may be patched to lines with long or short double-conductor flexible cords *o*. Patches are made with long or short single-conductor flexible cords *p*. To ground or open a line a metal peg is inserted in the proper jack.

TESTO CUT-OUT SWITCHBOARD

25. A standard switchboard large enough to accommodate the large number of wires passing through many test offices would more than cover the wall space available. To avoid this difficulty the testo cut-out switchboard has been devised. A portion of this board is shown in Fig. 16. The long vertical strips are divided into a number of sections, one of which is sufficient for each wire. As there are no disks, the connections are made by inserting in suitable holes in the vertical brass strips metallic plugs fastened to the two ends of a flexible cord. The test and operator's sets also terminate in plugs.

In Fig. 16, a relay and key are connected in series, that is looped, with lines *5* west and *5* east by means of plugs and flexible cords *w* and *x*; lines *2* east and *4* west are connected together by means of a flexible cord terminating in plugs that are inserted in holes *d* and *g*. Lines *1* east and *2* west, as they terminate on adjacent vertical strips, may be connected together by one peg in the hole *m*; and line *1* west is grounded by one peg inserted in the hole *v*. Although a great many wires may enter a test office for which the testo board is suitable, there are usually few connections or patches in use at any one time, consequently there are not enough cords or plugs on

the board to confuse the operator while making a change of connections.

According to the Telegraph Age, from which this description is abstracted, the use of this switchboard requires less

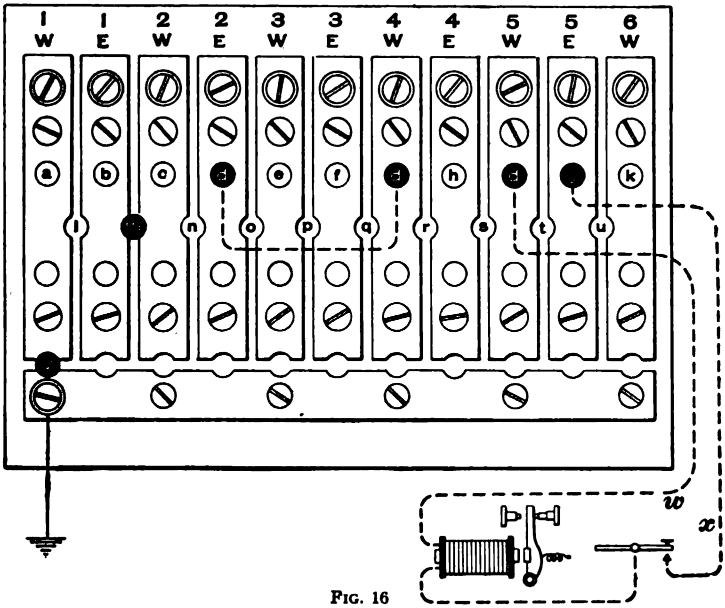


FIG. 16

switchboard space for each wire, while the operation of making patches is very simple. On a standard switchboard a long vertical strip is required for each wire, although only a small portion of it is useful at any one time.

MAIN-OFFICE SWITCHBOARDS

DOUBLE SPRING-JACK SWITCHBOARD

26. At terminal stations, provision must be made, not only for interconnecting in various ways the lines and office sets, but also for connecting the main-line and intermediate batteries in the circuit with either or both the above. At large telegraph centers, where thousands of wires terminate,

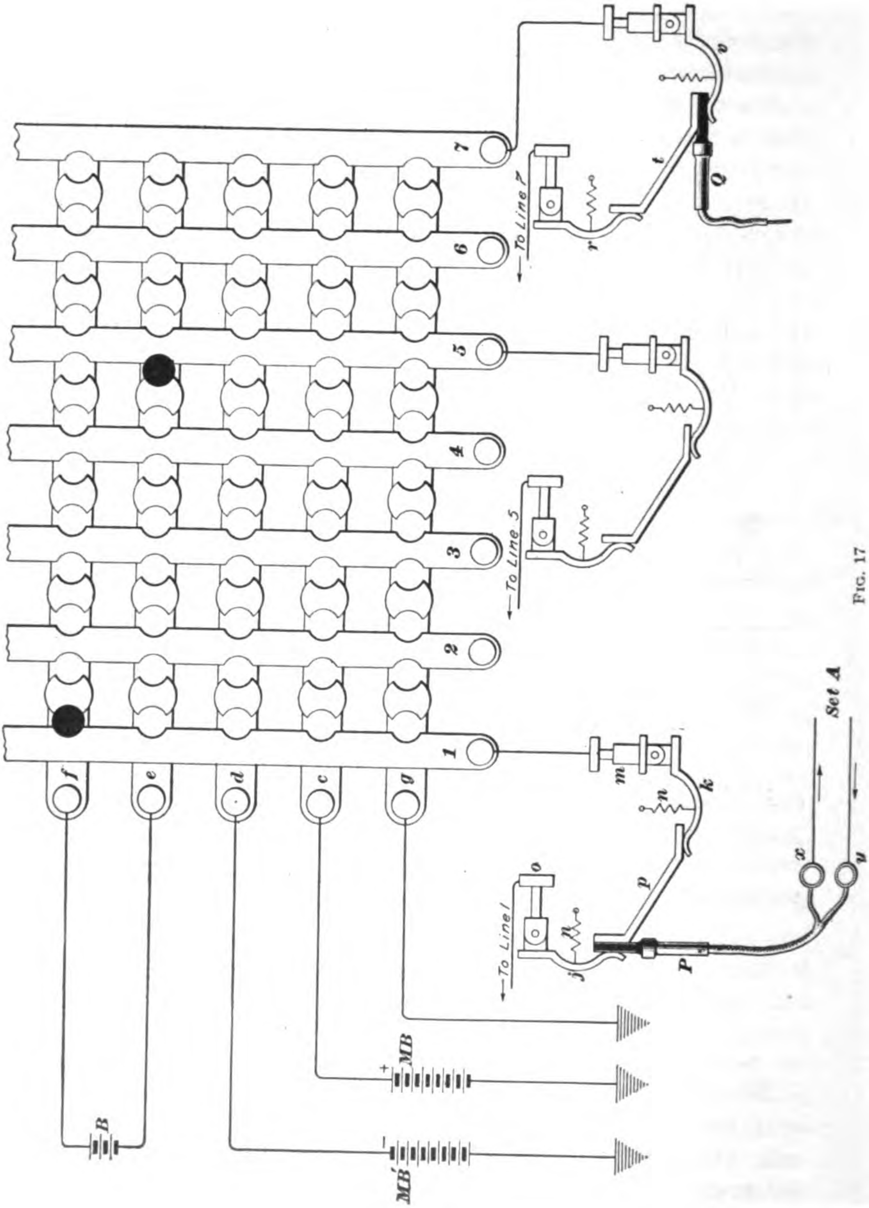


FIG. 17

and where all kinds of apparatus, such as repeaters, duplex and quadruplex sets, and ordinary relays and keys, and batteries of various potentials, are in use, the connections are apt to be, and especially to appear, very complicated. In order to make it as clear as possible, the various devices that, collectively, would form the complete arrangement at a terminal station, will be taken up separately. It would be very confusing, even if possible, to show all the connections in one diagram.

27. In Fig. 17 is shown a portion of a terminal switchboard. In some respects, it is quite similar to a way-office switch. All the disks in the same horizontal row are connected behind the board to the same brass strip, so that, behind the board, there are long horizontal brass strips, and, in front, long vertical brass strips, or *straps*, as they are called. By the insertion, therefore, of a plug in the front of the board, any horizontal row of disks can be connected to any vertical strap, as in the switches already described. The bottom row of disks is usually grounded and the lightning arresters are not attached to the switch, as on way-station switchboards, but are placed at the point where the lines first enter the building.

28. Double Spring Jacks.—Beneath each vertical strap is a switching device called a **double spring jack.** In the lower part of the figure are shown side views of three of these jacks, which have been drawn in a plane at right angles to that in which they actually belong, in order to show them. Such a switchboard is called a **double spring-jack switchboard.** The springs n normally keep the movable brass parts j and k firmly pressed against the brass piece p. The terminal m is connected to the vertical strap above it, and the terminal o is connected to a line wire. The brass pieces j and k are hinged, as shown, so as to allow the insertion of one or two wedges.

29. Wedges.—In connection with these spring jacks, two kinds of wedges, the single and double, are used. The double wedge consists of two flat pieces of brass, insulated

from each other by a central strip of hard rubber, and having a handle of the latter material. To the brass strips on each side of the wedge are fastened the ends of two wires, forming a flexible cord that leads through the binding posts x and y to office sets or other apparatus. The single wedge is like the double except that there is a brass strip on only one side of the insulating strip, and, consequently, only one wire is brought to the wedge. Wedges of this kind connect to duplex or quadruplex sets. The high-potential dynamo or battery leads for operating the duplex and quadruplex sets are run directly from the dynamo or battery to the desks, and not to the main switch. Consequently, the circuit is from the ground to the dynamo or battery, to duplex or quadruplex sets, to the wedge, spring jack, and out to line.

The cords should be, and usually are, so connected to the wedges that no strain can come upon the conductors themselves, especially not at the point where they are fastened to the brass part of the wedges. Otherwise, they would be continually causing trouble at these points through the breaking and crossing of the flexible conductors. The wedges are about 4 inches long, $\frac{1}{2}$ inch wide, and $\frac{3}{8}$ inch thick. The binding posts x and y are placed below a horizontal shelf or table that projects out just below the spring jacks, and on this shelf the wedges rest when not in use. The binding posts and wedges are connected together by flexible conductors, or *cords*, as they are called. On this shelf there are generally placed several keys, relays, and sounders for the use of the chief operator in testing out lines and circuits.

30. When a double wedge P is inserted as shown in Fig. 17, p connects with one side and j with the other side of the wedge, thus connecting, in the same circuit with the spring jack, whatever apparatus is joined through the binding posts x and y to the two sides of the wedge. When a single wedge Q is inserted in a spring jack, the wedge connects through t to r and to the line, while v, which rests against the hard-rubber side of the wedge, is thereby insulated and on open circuit. The double spring jack renders the insertion of additional sets

of instruments into the circuit an easy matter, for another wedge can readily be inserted between *p* and *k*.

31. Intermediate-Battery Connections.—In Fig. 17, a so-called intermediate battery *B* is connected to the two top rows of disks. An *intermediate battery* is one inserted in a line that does not terminate at this particular office. With this arrangement, two terminal offices can communicate with each other if their own batteries are too weak, or even if they have no batteries at all. Thus, for circuits about town, current generated by dynamos at a large central office can be used. As a rule, the local circuits at the small offices are not supplied with current from the central office, as are the line circuits. In large offices, many dynamos of different potentials are in use as intermediate batteries on lines that merely pass through the office.

32. In the double spring-jack switchboard, the positive pole of one main battery *MB* and the negative of another main battery *MB'* are connected to separate horizontal rows of disks, and the other poles of both batteries are grounded. In offices having two or more switchboards and two sets of main-line dynamos, each set consisting of several dynamos of different voltages, one board is connected only to the positive poles of one set of dynamos, and another board is connected to the negative poles of the other set of dynamos. This avoids the injurious short circuits that are apt to occur through careless plugging on the switchboard when both positive and negative poles of the dynamos are brought too near each other on the same board.

Where dynamos are used in the place of gravity cells for the main batteries, the disks in the rows to which the dynamos supply current are not joined together directly by a horizontal strip back of the board. Instead, each disk is connected through a separate incandescent lamp or other non-inductive resistance to the dynamo lead or bus-bar. The reason for using a resistance and arranging the connections somewhat differently when dynamos are used in place of gravity cells

will be explained in connection with the use of dynamos for supplying telegraphic circuits.

33. Possible Connections.—Since, in the ordinary spring-jack switchboard, all the line wires terminate at one of the spring jacks and all the office sets end in wedges, it is evident that any office set may be connected in circuit with any line; or several sets may be connected in the same line; two lines may be joined in one continuous circuit; either the positive or the negative pole of the main-line battery may be put to line; and, furthermore, an intermediate battery may be inserted in a line circuit. All this and more may be done by the mere shifting of wedges and plugs.

Any hole in the switchboard may be designated by specifying the vertical strap and the horizontal row of disks at the intersection of which the hole lies. For instance, to plug hole $7-c$ means to insert a plug in the hole between the vertical strap 7 and the disk in the horizontal row c.

34. Suppose it is necessary to connect at the switchboard shown in Fig. 17 the two lines 1 and 5, the office set A, and the intermediate battery B (positive pole to line 1) together. To do this, insert the double wedge P in the spring jack belonging to line 1, as shown, and located below strap 1, and put plugs in the holes $f-1$ and $e-5$. The circuit is then closed through the following path: From line 1 through one spring j and office set A – brass piece p of same spring jack – k – m – vertical strap 1 – plug in hole $(f-1)$ – disk in row f – intermediate battery B – e row of disks – plug in hole $(e-5)$ – vertical strap 5 – double spring jack below strap 5 to line 5. Two wedges may be inserted under the same spring of one jack, and two more, if necessary, under the other spring of the same jack.

35. In one large telegraph office there were five main-line switchboards, each having 30 horizontal rows of disks, and all together there were 1,025 vertical straps. These five boards were in different parts of the operating department. The local city lines, the eastern, western, northern, and southern lines

were collected at separate boards. The rows of disks were usually numbered from top to bottom at the extreme left.

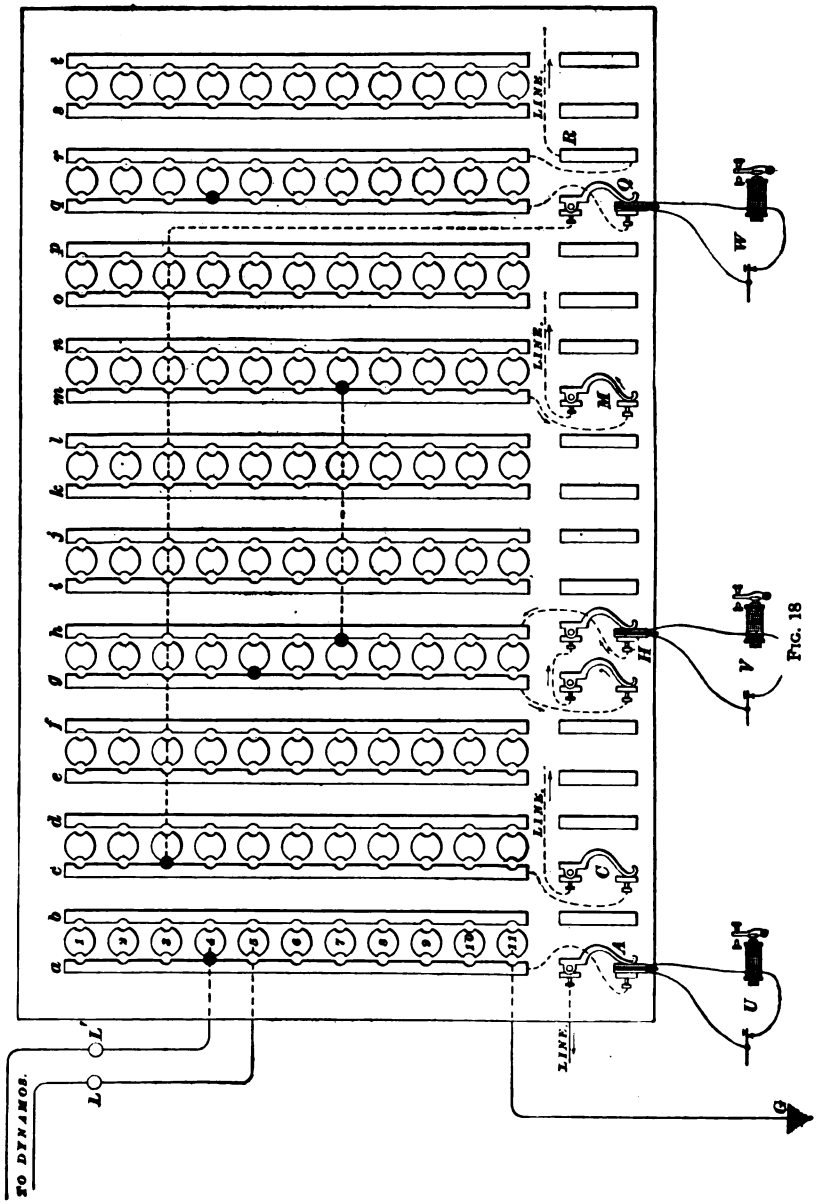
For the convenience of the chief operators at the different switches, there were communicating circuits, containing a key and sounder at convenient intervals on the switch tables. These switchboards were supported by means of fireproof iron frames with clear glass panels from the floor to the shelf at the front and two ends, and, above the switch proper, were frames containing the lamps that were used as resistances. There were about 2,100 such lamps.

36. Office Desks for Instruments.—In telegraph offices, even in comparatively small ones, the office sets are placed in groups of four on one table. The tables are about 4 ft.×6 ft., with a resonator and a typewriter for each operator. From each section, the wires from the line instruments are run to the switchboard, but all the local circuit wires go directly to the battery or dynamo leads.

SINGLE SPRING-JACK SWITCHBOARD

37. In Fig. 18 is shown a **single spring-jack switchboard** for use in a terminal office. Only two rows of disks, the fourth and fifth, are shown connected to the dynamos that supply current to the lines, but many more rows are usually connected in this manner. The disks in each row are not joined directly together behind the board, in this case, where dynamos are used, but are first connected to incandescent lamps or non-inductive resistance coils, and the other terminal of the lamp or coil is then joined to the dynamo lead or bus-bar. To avoid making the figure too complicated, only two disks are shown connected through lamps to the bus-bars. All disks in the same horizontal row, except those connected through lamps to the main-line dynamos, are joined together, as usual, by brass or copper horizontal strips behind the board. The bottom row is connected to the ground.

38. The bottom part of each spring jack is invariably connected to the vertical strap immediately above it, but the



a b c d e f g h i j k l m n o p q r s t
1 2 3 4 5 6 7 8 9 10 11
LINE
LINE
LINE
LINE
A
C
M
Q
R
H
U
V
W
G
L'
L
TO DYNAMOS.

Fig. 18

top terminals are connected in various ways. Some of the spring jacks have their top terminals connected to line wires, as shown at A, C, M, and R, and are called *line jacks;* some have their terminals joined to one horizontal row of disks, as shown at Q, and are called *single flips;* and some are joined together, as shown at H, and are called *double flips*. The single flip is connected permanently to some one horizontal row of disks, but the double flips, being connected to vertical straps instead, have the advantage of being available for connection with any unused row of disks. The office sets terminate at the board in double or single wedges, as already described. These boards are generally so long that the flexible conductors of a wedge cannot conveniently be made long enough to reach to any spring jack, and, for this reason, the double and single flips are necessary, and the manner of using them will now be shown.

39. Suppose that the office set V is to be connected to the line that is permanently joined to the spring jack M, and that the cord is not long enough to enable the wedge of the set V to be inserted directly in the jack M, and also that the voltage required is furnished by the dynamo connected to the fifth row of disks. The wedge of the office set V should be inserted in a double flip within its reach, as H. Then plugs would be inserted in holes $m-7$, $h-7$, and $g-5$, as indicated by the solid black circles at the holes designated. The circuit is then complete from the line through jack M – strap m – plug in hole $m-7$ to the seventh row of disks – plug in hole $h-7$ to strap h – office set V – double flip H – strap g – plug in hole $(g-5)$ – disk – lamp – dynamo – ground.

40. Suppose it is desired to connect a set W, terminating in a wedge near Q, to the line coming to spring jack C, and to use the potential of the dynamo supplying the fourth row of disks. Now, the upper part of the jack Q is permanently connected behind the board to the third row of disks. To make these connections, put the wedge in the jack Q and insert plugs in the holes $c-3$ and $q-4$. The circuit may be traced as follows: From the line terminating at the jack C through

jack to strap *c* – plug in hole (*c* – *3*) – back horizontal strip connecting together all disks in row *3* – wire connecting this third row to spring jack *Q* – jack *Q* and office set *W* – strap *q* – plug in hole (*q* – *4*) – disk – lamp – dynamo to the ground.

41. Office Set, Dynamo, and Line in One Circuit. Suppose that an office set *U*, Fig. 18, and the dynamo joined to the fourth row of disks are to be connected in series with the line coming to the spring jack *A*. The wedge of the office set *U* is inserted in the jack *A* and a plug is put in the hole *a* – *4*. The reader should now be able to trace out the circuit for himself. Both single and double wedges may be used with this board, and the intermediate batteries may be

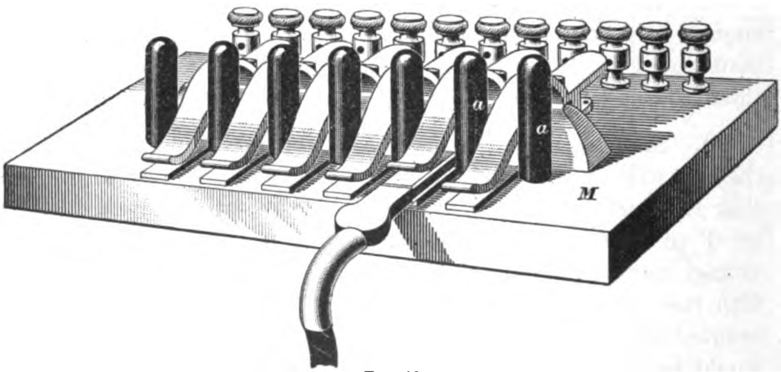


FIG. 19

connected as on the preceding switchboard, or, as is often done, the leads from the intermediate battery or dynamo may be terminated in a double wedge.

42. Single Spring Jacks.—A row of six single spring jacks, mounted on a separate base, is shown in Fig. 19. The base *M* is made of good insulating material, such as hard rubber or thoroughly dried and seasoned wood, and the jacks are separated by pillars *a* of hard rubber. There are two binding posts for each jack, one being connected to the top or movable part of the spring jack, and the other to the flat under piece. The spring that keeps the two parts of a jack firmly pressed together is under the movable part and hidden from view. A wedge is shown inserted in one of the jacks.

The weak parts of a spring jack are the spring and pivot. The spring sometimes stretches and does not hold the lips tightly together while the pivot may rust or become worn. A defective spring can be readily replaced, but when the pin becomes rusty it frequently causes momentary openings in the circuit that close the moment a wedge is inserted for testing purposes. This is one of the most annoying troubles as the spring jacks become old, for it is not apparent to the eye and only after openings occur successively in a jack, is one warranted in ordering its removal and overhauling. Jack pins should be carefully and frequently inspected for rust and wear.

43. Elimination of Errors in Connecting.—To avoid the accidental connection of two wires together on one row of disks and to enable the chief operator to more easily follow with his eyes a long horizontal row of disks, some switchboards have the disks in every other pair of disk rows, for instance, in horizontal rows *3*, *4*, *7*, *8*, *11*, Fig. 18, made with a saucerlike surface, or marked with a drill, the intermediate pairs *1*, *2*, *5*, *6*, *9*, *10*, etc., being left perfectly flat. Thus, should the upper concave row of disks in any pair, for instance, row *3* of the pair *3*, *4*, be selected for the purpose of joining two wires across the board, the chief operator making the connection would have to be at least four rows out of alinement before he could find another similarly located row with a similar saucer-like surface. Such a mistake would seldom, if ever, be made. Furthermore, this improvement involves no new parts and disks on old switchboards can readily be so marked.

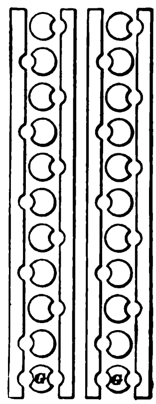


FIG. 20

44. Practically the same object is accomplished on a switchboard installed in 1894, in New York City by the Postal Telegraph-Cable Company. The upper of each two rows of disks for each pressure on the main-line board is drilled only on the right side, while the lower row of each two rows of disks is drilled only on the left side, as shown in Fig. 20, instead of drilling all disks on both sides as usual. Each disk is connected,

through a non-inductive resistance, to the dynamo leads. Thus the possibility, as on many switchboards, of inserting two plugs in contact with one and the same disk, and therefore of supplying two lines through one coil is avoided. The coils are all wound on metal or porcelain tubes mounted on heavy slate boards supported by iron frames, so that the construction is as fireproof as it can be made.

LOOP SWITCHES

45. In addition to the terminal switches already described, the very large offices have what are called **loop switches.** These switches make an extremely convenient and flexible system whereby many changes and combinations may be made between the lines and the various telegraphic apparatuses. It allows the concentration of the various multiplex and repeater sets in one room, under the supervision of a few experts, and yet, by means of the loops, the branch offices can receive or send through these sets. It also makes possible the interconnection of every variety of repeater, both with the lines and the multiplex sets. The use and advantages of loop switches will be better understood and appreciated after repeaters and multiplex sets have been explained.

46. Loop switches vary quite a little in arrangement. In one large telegraph office, the loop switch consisted of five horizontal rows of spring jacks, making a total of about 375. These spring jacks were of the usual construction, and 126 of them were the terminals of flexible cords, the other ends of which terminated in wedges for insertion in the jacks at the main switches. These latter wedge circuits are called *flying loops*.

On a table or shelf in front and below the jacks were about 450 double wedges with flexible two-wire conductor cords of the form already shown and described. These wedges formed the terminals of the branch-office and newspaper loops, Milliken repeaters, intermediate dynamos, and other circuits and apparatus. A branch-office or newspaper loop is simply two wires running to the same branch or newspaper office.

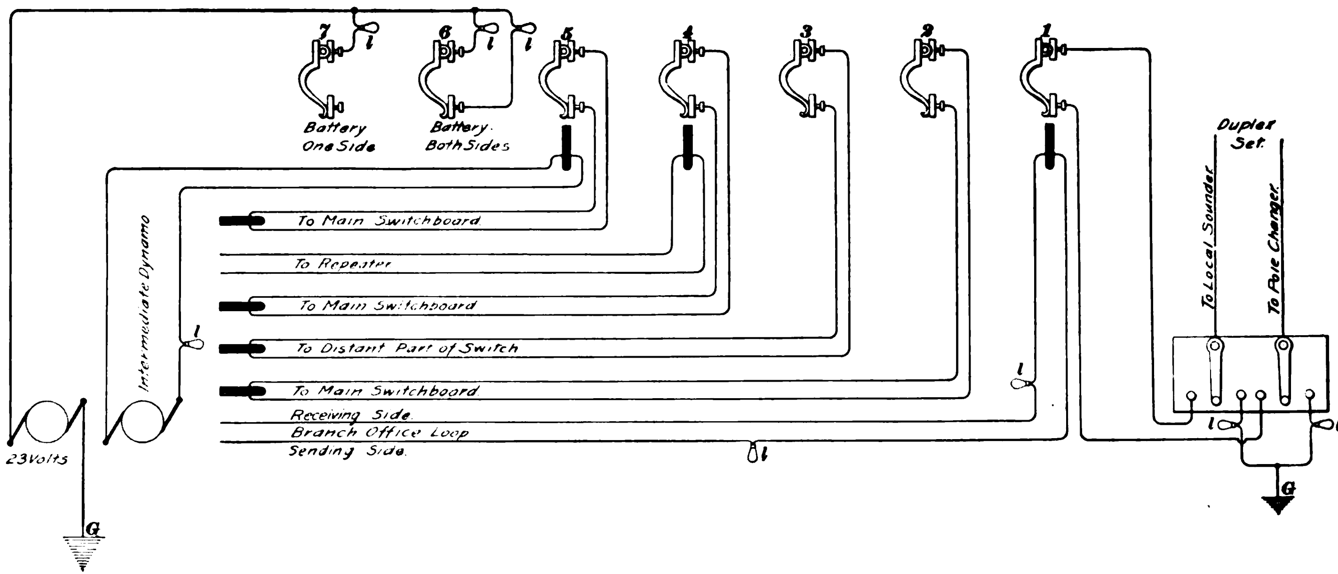

7
6
5
4
3
2
1
l
Battery
One Side
Battery
Both Sides
Duplex
Set.
To Local Sounder
To Pole Changer
To Main Switchboard
To Repeater
To Main Switchboard
To Distant Part of Switch
To Main Switchboard
Receiving Side.
Branch Office Loop
Sending Side.
Intermediate Dynamo
23 Volts
G

FIG. 21

In these 450 loop circuits there were inserted 900 lamps, one lamp in each side. These lamps varied in resistance from 20 to 80 ohms, a lamp of such a resistance being used in each side as brought the resistance of that side up to 92 ohms, or as near that as convenient.

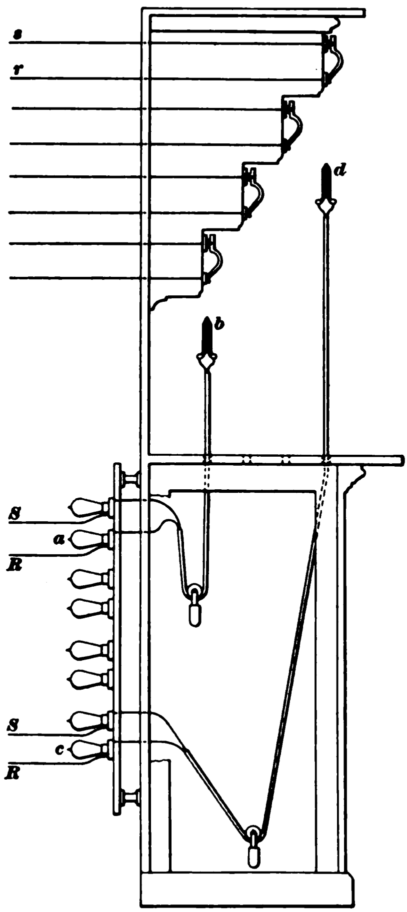


Fig. 22

47. A good idea of a loop switch may be obtained from Fig. 21. Those circuits lettered *To Main Switchboard* are the flying loops. One jack, as indicated, is connected to a wedge for use at a distant part of the same loop switchboard. Every duplex, quadruplex, and certain repeater sets in the office are connected to jacks at this board. A branch-office loop is shown terminating in a wedge just below a jack in which the wedge would be inserted for use in connection with a duplex telegraph set. One wire is called the *sending side* because, by means of a key at a branch office, an operator there controls the pole changer of a duplex set located at the main office. In the receiving side at the branch office and at the main office are sounders controlled by the duplex apparatus located at the main office. Thus, the complicated duplex sets are kept at the main office, while only keys and sounders are necessary at branch offices. A quadruplex set can be used in much the same way.

48. An end view of a loop switchboard used in some Western Union Telegraph offices is shown in Fig. 22. Instead of terminating the outside lines in the jacks and the table sets in wedges, as on a main switchboard, the office circuits running to repeater tables, multiplex local circuits, dynamos, etc. terminate at the spring jacks of the loop switchboard, while the outside loops, some repeaters, intermediate batteries or dynamos, and main-switchboard wedges are connected to wedges *b* and *d* that normally rest on the shelf of the loop switchboard. The loop and other circuits, when desired, are run through resistance lamps *a* and *c* just before attachment to the wedges. Where the spring jacks are connected to multiplex sets, the upper part of the jack is connected by wire *s* to the sending side of the local circuit while the lower part of the jack is connected by wire *r* to the receiving side of the local circuit. The wedges are connected in the same order, as indicated by the letters *S* and *R*.

49. Dynamo in Loop Circuit.—A 23-volt dynamo, for use in loop circuits to branch offices, is shown in Fig. 21 connected through lamps to one side of jack No. *7*, and to both sides of jack No. *6*. This allows one or both sides of a branch-office loop to be supplied with current from the 23-volt dynamo. In some cases, several branch offices, even as many as ten, are connected up in one circuit.

50. Dynamos as Intermediate Batteries.—A number of special dynamos, used as intermediate batteries, are connected to wedges. These intermediate dynamos deliver current at from 50 to 125 volts. In Fig. 21, only one dynamo is shown connected in this manner. By means of the flying loops, these dynamo circuits may be thrown as required into any of the main-line jacks. The repeater, duplex, and quadruplex circuits that are brought to this board will be better understood after such systems have been explained.

51. Postal Telegraph Loop Switch.—The Postal Telegraph-Cable Company's loop switches are arranged in a somewhat different manner, there being two wires in a

branch-office loop with a common ground connection, as will be seen in connection with the descriptions that will be given later of this company's duplex and quadruplex systems.

SKIRROW SWITCHBOARD

52. There was installed in 1899 in the New York office and in 1900 in the Philadelphia office of the Postal Telegraph-Cable Company, a system of switches invented by Mr. J. F. Skirrow. In a large office, the flexible switching cords cause considerable trouble. They become tangled and their available length thus shortened, and a defective cord not only causes delay before it can be replaced, but may be the cause of a disastrous fire.

Where a number of line switchboards are used in a large office, it has been customary to bring the loops and desk sets in one part of the room or building to a board that contains a given number of main-line wires, these loops and sets being used on these wires. It is often desirable, however, to connect loops and desk sets to other boards than those to which they are connected permanently. On the boards previously in use by the Postal Telegraph-Cable Company, this was usually done by transferring the loop or line to another board by means of the rows of disks running horizontally through each board, the connection being made by placing an ordinary pin or plug at both boards on any given row of disks. Before using the row of disks, it would be necessary to see that this row was not in use at any other part of any board. The number of such transfer connections is necessarily limited, and, where many boards are used, special wires are run from board to board where most needed.

53. The new arrangement is about as shown in Fig. 23. *W* and *E* represent small sections of two main-line switchboards, and *C* a central switchboard, the function of which is similar to that of a central exchange telephone switchboard, and will be explained presently. In the table, or shelf, at the switchboards, specially designed pin jacks are placed; an enlarged view of a pin jack *J* and plug *P* is shown. To the

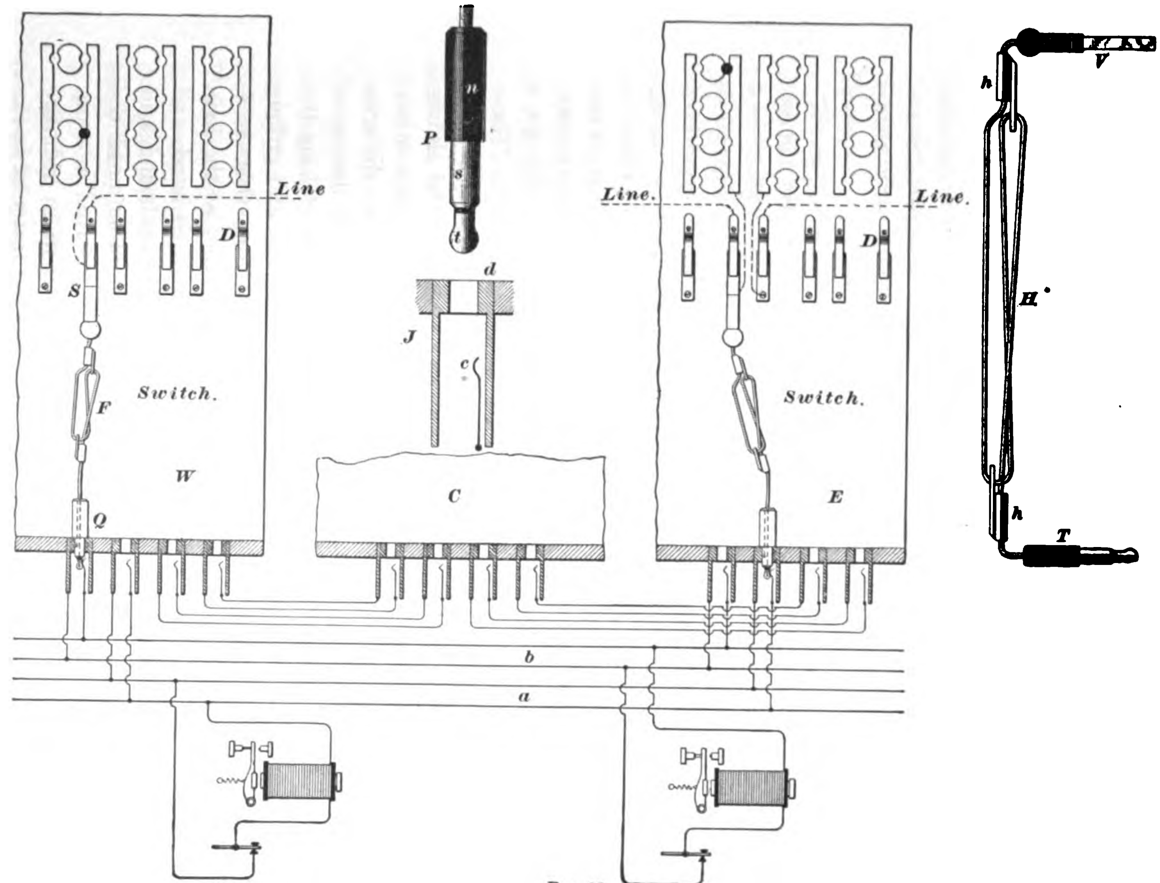


FIG. 23

shell of the jack *J* is attached one wire and to an insulated spring *c* within the shell another wire is attached. The spring and shell never touch each other, whether the plug is out or in, so that the two wires brought to it never touch each other. A row of these pin jacks is shown in the figure in the shelf below the switchboard. Special plugs fit into these pin jacks. They have two wires running into them, one of which is fastened to the rounded tip *t* and the other to the sleeve *s*, the tip and sleeve being insulated from each other. The plug is furnished as usual with a hard-rubber, or fiber, handle *n*.

54. When a plug *P* is inserted in a jack *J*, the tip *t* makes contact with the spring *c*, and the sleeve *s* makes contact with the shell or sleeve *d* of the jack. At the right of Fig. 23 is shown one plug *T* and an ordinary double wedge *V* connected together by two flexible wires enclosed ina flexible covering *H*. The double-contact wedge *V* has already been described in connection with other main-line switchboards. The cord *H* can be very quickly extended to about three times its normal length, and as readily shortened again, by means of sliding blocks *h* having a ring or eye through which the cord is looped. These sliding blocks *h* consist of a cylinder or tube arranged to slide easily on the exterior of the cord *H*. By causing the sliding blocks *h* to approach and recede with respect to each other, the loop may be shortened or lengthened, and the distance between the wedge *V* and the plug *T* is increased or decreased to suit the requirements of any particular case. By taking the wedge *V* in one hand and the plug *T* in the other, and pulling in opposite directions, the cord is lengthened, the loop shortened, and the sliding blocks *h* moved toward each other as the loop is contracted. By taking a sliding block *h* in each hand, and pulling them in opposite directions, the loop is lengthened, and the plug and wedge made to approach each other until the minimum extent is reached. When a plug is inserted in a pin jack, as at *Q*, and the double wedge is inserted in an ordinary spring jack, as at *S*, the circuit of the two wires fastened to the pin jack *Q*, is extended through the flexible cord *F* to the spring jack *S*.

55. The rows *D* are ordinary single spring jacks for use with the double wedges. They are connected as usual: the lower side to the vertical brass strip immediately above it and the upper terminal to a line wire. Above these are the usual vertical brass strips and disks. But there is needed in this form of switchboard only those horizontal rows of disks that are connected to the main batteries or dynamos. Consequently, instead of 20 or 30 horizontal rows of disks, as is usual in large boards, only a few are necessary, four being shown in this figure.

When the switchboards are in use, all idle cords are removed from the board; therefore, a defective cord can be very quickly replaced by a good one, as the cord is in no way permanently connected to the board. Furthermore, there are no cords, slack or otherwise, under the shelf, as in the older forms of switchboards. One pin jack at each board is connected to the same pair of wires. Consequently, there are as many pin jacks connected in multiple to the same pair of wires as there are main-line boards. To each such pair of wires, as *a* and *b*, in Fig. 23, there is connected one set of office instruments, or one loop circuit running to a district, branch, or newspaper office. Consequently, it is possible to bring every loop and desk set in an office in multiple to every board, thus making them available at each board without transferring and consequent loss of time. Under a 50-wire spring-jack board of the present type, it is possible to place from 1,000 to 2,500 of these pin jacks, representing from 2,000 to 5,000 wires, and, by a modification of the present shelf system, the number of such multiple circuits may be very largely increased. This is evident from the fact that on a telephone switchboard it is very common to have 3,000 to 4,000 jacks of even more complicated design placed on one section of a switchboard, all within the reach of one operator, seated in a chair.

56. In addition to the foregoing arrangement, there could be a row of these pin jacks at each board, the wires from which run to similar jacks at a central board *C*. At this board, the jacks could be combined as desired, and it would be possible,

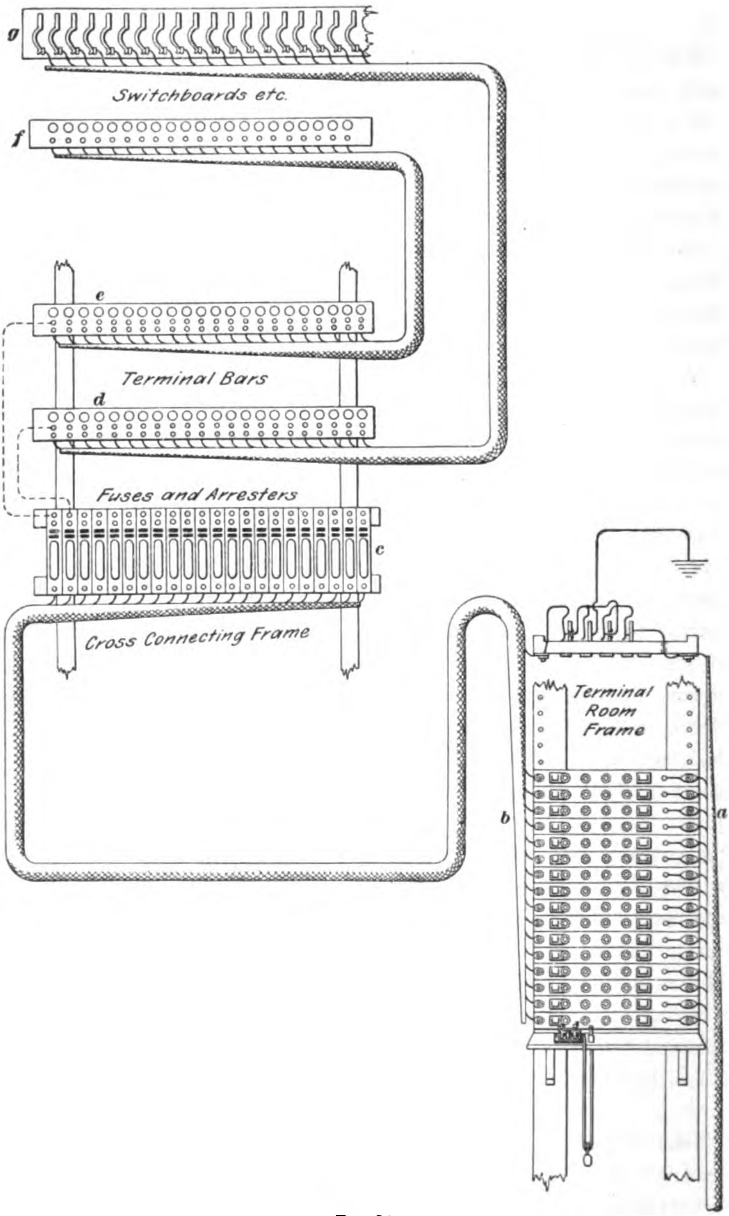

g
Switchboards etc.
f
e
Terminal Bars
d
Fuses and Arresters
c
Cross Connecting Frame
Terminal Room Frame
b
a

FIG. 24

by this means, to quickly transfer any or all the main-line wires from one board directly to other boards. The connecting link to be used between two pin jacks at the central board *C* would be a flexible cord similar to that shown in Fig. 23, but terminating in two similar plugs, and not in one plug and one double wedge. In the Philadelphia office there is a so-called leg board, made up of four rows of ordinary spring jacks, 50 in each row. The local connections to every quadruplex set in the room and all branch-office and newspaper loops terminate at this leg board. Rows of pin jacks are placed at the base of each board, all being connected in multiple; one row is used for making transfer connections, another for repeaters, another for desk sets, another for loops, etc., with sufficient spare jacks for future growth.

TERMINAL FRAMES

57. In Fig. 24 is shown the arrangement of terminal and cross-connecting frames in Postal Telegraph-Cable offices. The cables from the street terminate on the right side *a* of the terminal-room frame. Each conductor is connected to a terminal-jack bar and each bar has a looping, grounding, and patching jack for test purposes. From the side *b*, cables run to the cross-connecting frame *c*, which is usually placed behind the switchboard in the operating room. On this frame, each line passes through a fuse and arrester, then it is cross-connected to frames *d* or *e* from which the lines run to the main switchboard *f* or to the loop switchboard *g*. Wires from the operators' tables, repeater tables, also duplex, quadruplex repeater, and other circuits terminating in wedges on the various switchboard shelves, and resistance coils used in multiplex and other local circuits are brought to frame *d*. Some of these pass to the loop switchboard but others are cross-connected to frame *e* and carried to the main switchboard.

TROUBLES IN WEDGES AND JACKS

58. Open Circuit in Spring Jack.—Telegraph spring jacks seem so substantial that a defect in one may exist for a long time before the source of the trouble is suspected and located. A rusty or worn hinge pin, which cannot be seen, may cause trouble for a long time. The only reliable remedy is to remove the whole jack from the board and put in a new hinge pin. This defect should always be suspected where loops close simultaneously when a branch-office-test-set wedge is inserted at the switchboard or when the position of the wedge in the jack is altered. Of course a loop may be temporarily open due to dirt or dust between the lips and the wedge, which by the insertion of the test wedge may have been removed. For this reason a defective pin is not usually suspected, especially when it is impossible to reopen the circuit by moving the wedge when trying to locate the trouble. Nevertheless, when such loop openings have occurred daily for some time, while all the connections appear normal and the line closes when a test-set wedge is inserted in the spring jack, remove the jack at once and overhaul it. Nearly all old or much-used switchboards contain one or more spring jacks that cause trouble daily so that spring jacks should be frequently overhauled.

59. Loose Connection in Spring Jack.—A common spring-jack defect is the opening of a duplex loop on the receiving side due to the loosening of the nut that should hold the wire fast to the brass plate, termed the under side of the ~~tip~~ lip. This should be the first point examined when looking for this trouble and to prevent it, these nuts should be examined at frequent intervals. The sending side, or upper lip, is not so likely to become loose, but the upper-lip connections should be examined occasionally.

TELEGRAPHY
(PART 3)

THEORY OF ELECTRIC CIRCUITS

CHARACTER OF ELECTRIC CURRENTS

DIRECT CURRENT

1. Any electric current may be classified either as *direct current* or as an *alternating current*. The abbreviations for these are D. C. for direct current, and A. C. for alternating current. A **direct current** may be defined as a current that

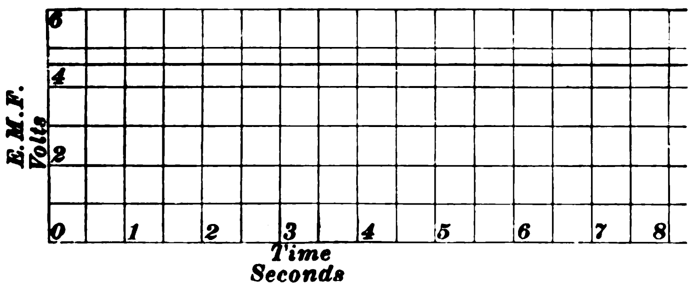


FIG. 1

always flows in the same direction through the conductor or circuit; it may be *continuous* or *pulsating*.

A continuous current is a non-pulsating, direct current; its strength may vary, but not in a pulsatory manner. A direct electromotive force having a constant value during succeeding

intervals of time will cause a perfectly steady continuous current to flow through a circuit of constant resistance.

A **constant direct current** is a continuous, or pulsating, direct current whose average strength does not change. A continuous current of constant strength, that is, a constant continuous current, may be represented by the heavy straight line parallel to the axis of abscissas, as in Fig. 1. Constant-potential dynamos, which are used for direct-current incandescent lighting and primary and storage batteries, furnish continuous currents.

2. A **pulsating current** is one that always flows in the same direction, but the electromotive force or resistance varies periodically so that the current consists of distinct impulses, or rushes of current. In Fig. 2, (*a*), (*b*), and (*c*) represent three possible curves of pulsating currents. In (*a*), the fluctuations of the electromotive force, or current, occur between a maximum and zero, while in (*b*) the minimum is about .7 of the maximum; (*c*) represents a slightly different type of curve, in which the minimum is about .85 of the maximum. It will be noticed that either of the last two quite closely approaches a continuous current.

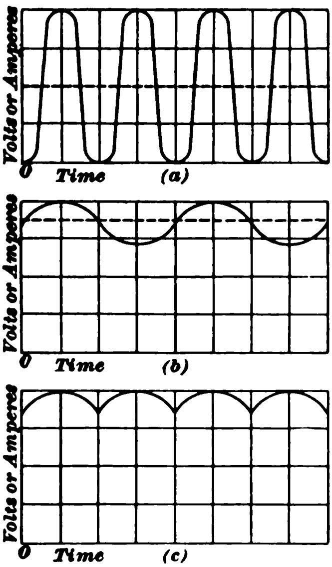


FIG. 2

3. **Current in a Telegraph Circuit.**—The current in a simple Morse telegraph circuit is a form of pulsating current. It is caused by alternately applying a constant electromotive force to, and withdrawing it from, a circuit of constant resistance by the closing and opening of the circuit at the telegraph key. Such a current is illustrated in Fig. 3, in which the current rises almost instantly from zero

to its maximum strength when the key is closed; it then remains constant or continuous about the duration of a signal, and falls suddenly to zero when the key is opened. During the interval of a signal, unless the speed of transmission is very rapid, or the product of the resistance and electrostatic capacity of the line is very large, the current is practically continuous and its strength may be calculated by Ohm's law. If the circuit possessed only resistance, and no inductance or capacity, the current would rise and fall instantly, as shown in Fig. 4.

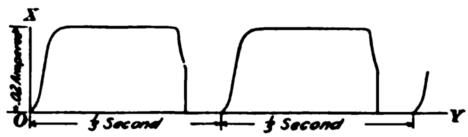


FIG. 3

As the speed of telegraphing is increased, the flat portions at the top of the curve decrease in length and may disappear entirely. The current may commence to decrease before it reaches the maximum value it otherwise would attain, on account of the time interval of one signal being short compared to the time constant of the circuit. A very rapidly pulsating, or fluctuating, current follows more nearly, in some respects, the law for alternating currents than that for direct currents. If the zero horizontal axis is shifted to a position midway between the minimum and maximum values of such a pulsating current, as shown by the dotted lines in Fig. 2 (*a*) and (*b*), the current may be looked upon as a direct current up to that line, above and below which it increases and decreases, respectively, according to the laws for alternating currents, which will be given later.

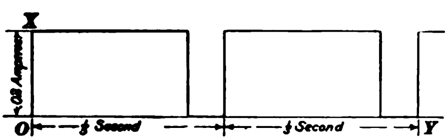


FIG. 4

ALTERNATING CURRENTS

4. An **alternating current** may be defined as a current that is continually reversing its direction in the circuit; consequently, the electromotive force, as well as the current, alternates between two opposite maximum values. The curve

of electromotive force, and also the curve of the current, will therefore be on both sides of the horizontal reference line *A B*, Fig. 5.

In cable telegraphy, the currents are alternating in character, although the curves representing such currents are very irregular in shape. Several very rapid telegraph systems have been devised, in which alternating or reversed currents are employed; and as some such systems may come into use, it is desirable that the reader should be prepared to understand them.

5. By Delany's automatic chemical method, employing currents flowing alternately in opposite directions, from 2,000 to 3,000 words per minute have been transmitted. By the

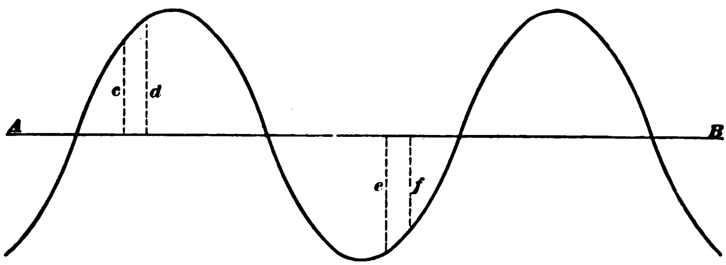


Fig. 5

system of Crehore and Squier, in which simple sine alternating currents are employed, over 600 words per minute have been sent by using their own transmitter and the Wheatstone recording receiver. With their own transmitter and receiver, they have sent messages at the rate of 1,200 words per minute, and claim to be able to send 3,000, and by duplex transmission, which is possible with this system, twice that many, or 6,000 words per minute. By the system invented by Pollak and Virag, of Austria, messages at the rate of 1,000 words per minute were sent between New York and Chicago on December 3, 1899. Pollak and Virag claim to be able to send over 1,700 words per minute.

6. Simple Harmonic Motion.—A curve like that shown in Fig. 5 represents what is termed **simple harmonic motion,**

which is a most important form of vibration, not only in alternating currents, but in all branches of physics relating to wave motion. If a pin head p', Fig. 6, on a disk D revolving at a uniform speed is allowed to cast a shadow perpendicularly on a plane at right angles to the disk, the movement of this shadow will be a simple harmonic vibration. The movement of the shadow, of course, will be in a straight line, as shown at $p\ p$. Starting at one end of its path, the shadow will move slowly at first, but with increasing velocity, until the middle point of its path is reached. Here the velocity will be a maximum, for after passing this point, it will decrease more and more rapidly, until it comes to rest momentarily at the other end of the path. The direction of motion will then be reversed, and the shadow will again attain its maximum velocity in the other direction at the center point in its path, and will again come to rest momentarily at the starting point.

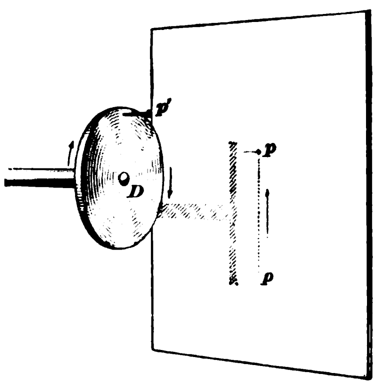


FIG. 6

7. Simple harmonic motion may be defined as the movement of the projection on a fixed straight line of a point moving uniformly in a circular path. This definition will perhaps be made more clear by considering Fig. 7. Let p' be a point moving with a uniform velocity in a circular path of which the center is O, the direction of motion being as indicated by the curved arrow. The projection p of the point on the vertical diameter of this circle will move from one end of this diameter to the other in exactly the same manner as did the shadow of the pin head in Fig. 6. If, while the projected point p is moving along the vertical diameter with harmonic motion, it should be caused to trace its course on a sheet of paper by drawing the paper with a uniform motion from right to left under the point, the path on the paper would be as indicated by the

curved line $A\,B\,C\,D\,E$. The beginning A of the curve corresponds to a time when the point p' was at the point A' on the circumference. As the movement progresses, the curve gradually rises to a maximum height at B, which is reached when the point p' has rotated from its original position A' through 90° of the circle to its highest position p'''. The curve then descends and reaches the zero line at C, when the point p' has rotated through an angle of 180° to p''''. The next half

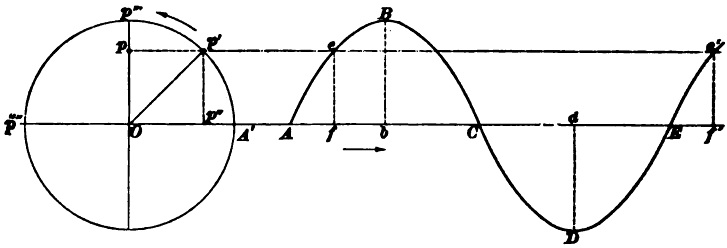


FIG. 7

of the revolution of the point p' causes its projected point p to trace a curve below the line exactly similar to that traced by the first half above the line.

8. Curve of Sines.—The curve shown in Fig. 7, which is used to represent simple harmonic motion, may also represent all the values of the sine of an angle, while the angle is uniformly increasing from 0°, and is therefore termed the **curve of sines,** or the **sine curve.**

The distances from the point A in a horizontal direction may be considered as measures of the angle through which the point p' or the line $O\,p'$ has rotated. Similarly, the ordinate at any point of the curve $A\,B\,C\,D\,E$, that is, the perpendicular distance from any point in the curve to the base line, as $e\,f$, is a measure of the sine of the angle represented by the horizontal distance of that point from the reference point A, as $f\,A$, for

$$\sin A'O\,p' = \frac{p'\,p''}{O\,p'},$$

or

$$p'\,p'' = O\,p' \sin A'O\,p' = r \sin A'O\,p',$$

where r is the radius of the circle, or the amplitude of vibration, as it is called.

Now, $p' p'' = O p$, and as any ordinate $e f$ at any point on the curve is always equal to the distance $O p$ for the corresponding angle, any ordinate on the curve will be

$$e f = r \sin A' O p',$$

where $A' O p'$ is the angle corresponding to the position of the point e on the curve.

DIAGRAMMATIC REPRESENTATION OF ELECTRIC WAVES

9. Analysis of Curves.—The successive values of an alternating current, or of an alternating electromotive force, may be represented by means of curves, as has already been done in the case of pulsating currents. In the right-hand portion of Fig. 7, the horizontal line $A E$ may be considered to represent time, while the vertical lines $f e$, $b B$, $d D$, and $f' e'$ may be considered to represent the instantaneous values of the current, or electromotive force, at corresponding particular moments. The curve $A B C D E$ will first be assumed to represent the values through which the current passes in the course of a complete cycle. The distance $A E$ along the horizontal line will then represent the time taken for the current to pass through a complete cycle, and the distance $A f$ will represent the time in which the current has risen from zero to a value represented by the line $e f$. The distance $A b$ will represent the time taken for the current to pass through a quarter cycle, and the line $B b$ will represent the maximum positive value of the current. During the time represented by the distance between b and C the current decreases, its value at any time being represented by the perpendicular distance, or ordinate, between the horizontal line $A E$ and the curve. At the point C, which corresponds to the end of the first half cycle, the current passes through zero and begins to increase in the negative, or opposite, direction. The distance $A d$ represents the time of three-fourths of a cycle. At the point D, the current has reached its maximum negative value; after passing beyond this point the current gradually

decreases to zero at the point E, which marks the end of the first complete cycle.

10. Amplitude.—In the case of simple harmonic motion, the amplitude of vibration is the maximum displacement of the point p from its center position O. Thus, in Fig. 6, the amplitude would be represented by one-half the length of the line $p\ p$, and, in Fig. 7, by the radius of the circle, or by the line $b\ B$ or $d\ D$. Similarly, in the case of an alternating current or an alternating electromotive force that follows a sine curve like that in Fig. 7, the maximum value is represented by the amplitude of the curve, that is, by the line $b\ B$.

11. Cycle.—A complete vibration up and down of the point p, corresponding to one rotation of the point p' through 360°, is termed a **cycle.** A complete cycle will, therefore, be represented by the part $A\ B\ C\ D\ E$ of the curve shown in Fig. 7, $E\ e'$ being part of the next cycle. In its vibration, the point p has completed one full cycle and has started on the next, being at the time shown at the point e' on the curve. The distance $A\ E$ is the length of one complete wave, and is called the **wave length.**

If the curve represents an alternating current, or electromotive force, then, when the alternating current, or electromotive force, starts at A, passes through all the positive values (that is, along the curve $A\ e\ B\ C$ above the axis), returns to the axis at C, passes through all the negative values (that is, along the curve $C\ D\ E$ below the axis), and returns to the axis at E, it is said to have made one complete cycle.

It is evident that simple harmonic motion, although taking place in a straight line, is very closely allied to circular motion, and it is therefore customary to deal with it by means of angular measure. Thus, a complete cycle is represented by 360°, or by $2\ \pi\ r$, where r is the radius of the circle, or the amplitude of vibration; one-fourth of a cycle is represented by 90°, or $\frac{\pi\ r}{2}$. Wherever π, which is a Greek letter pronounced *pi*, is used it stands for 3.1416.

12. Alternation.—As that portion of the curve which in Fig. 7 is included between *A* and *C*, or between *C* and *E* represents an **alternation**, a cycle is equivalent to two alternations.

13. Frequency.—The number of complete cycles occurring in 1 second of time is called the **frequency** of the vibration or of the alternation. The term frequency is sometimes misused by making it represent the number of alternations, half vibrations, or half cycles that occur in 1 second.

14. Period.—The time that elapses during one complete cycle is termed the **period** of a vibration. Thus, if P represents the period and n the frequency, $P=\frac{1}{n}$. In Fig. 7, the time required for the wave to move from A to E is the period of vibration. The horizontal distance measured along the line $A\,E$ may be taken as a measure of the time elapsing during the passage of the point p from any point on the diameter of the circle to any other point, or it may be taken as a measure of the angle through which the point p' has rotated from its original position A'. Thus, if it takes the point p just 4 seconds to pass from the center point O through a complete cycle back to that point, it is evident that the distance $A\,E$ will represent the time of one complete cycle, that is, 4 seconds. It may also represent the angular rotation of the point p', and in circular measure, will be 360°, or $2\,\pi\,r$. In a like manner, the distance $A\,b$ will represent a time of 1 second, because it is one-fourth of $A\,E$, or an angular rotation of 90°; the distance $A\,C$ a time of 2 seconds, or an angular rotation of 180°; and the distance $A\,d$ a time of 3 seconds, or an angular rotation of 270°.

15. Phase.—The portion of a cycle through which a vibrating point has passed at a given time is called the **phase** of the vibration, and is usually expressed in angular measure. Thus, the point B on the curve in Fig. 7 represents a phase of 90°; the point C, a phase of 180°; the point D, 270°; and the point E, 360°, or a complete cycle.

ELECTRIC PROPERTIES OF A CIRCUIT

ELECTROSTATIC CAPACITY

16. If a condenser C is connected to a generator G of alternating currents, as in Fig. 8, its terminals will be subjected to electromotive forces varying rapidly from a maximum in one direction to a maximum in the other direction. As the condenser receives a charge from the lines or discharges itself back into the line, currents will flow into or out of it, according to whether the pressure at its terminals is increasing or decreasing.

The amount of current flowing into or out of the condenser depends on the rate of change of the electromotive force at its terminals; but the amount of the charge in the condenser at a given instant depends on the instantaneous value of the electromotive force, and not on its rate of change. Evidently, as long as the electromotive force at the condenser terminals does not change, no current will flow into or out of the condenser, but if the electromotive force across the condenser terminals is raised, a current will flow into the condenser, and if lowered, a current will flow out of the condenser. The faster these changes in the potential across the condenser terminals take place, the greater will be the current flowing into or out of the condenser.

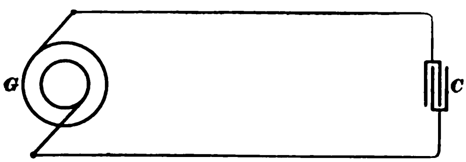


FIG. 8

ALTERNATING-CURRENT LAWS

17. Opposition Due to Resistance.—Ohm's law asserts that a continuous current is equal to the electric pressure in a circuit divided by the electrical resistance of that circuit. This law is nothing more than a special statement of a condition that may be recognized as universally applicable to the phenomena of nature. The general statement may be put thus:

The result of an effort is equal to that effort divided by the opposing resistance. For instance, if an elastic material is stretched, the amount of stretch will depend on the ratio of the pull to the elastic resistance of the material; if a heavy block is pushed along the floor, the velocity of the block will depend on the ratio of the force exerted to the frictional resistance opposing the motion; and so it is possible to go on indefinitely illustrating the general applicability in nature of this statement that the result is dependent on the ratio—effort divided by resistance.

This gives for the flow of continuous currents the rule that the current flowing (result) is equal to the pressure (effort) divided by the opposition to the current flow (resistance); but in the case of continuous currents, there is no opposition to the flow of the current except electric resistance, that is, the resistance that is determined by the nature, temperature, and dimensions of the conductor, whence we have Ohm's law, $I=\frac{E}{R}$, for the flow of continuous currents.

18. Opposition Due to Resistance, Inductance, and Capacity.—The fundamental law of the flow of alternating currents follows directly from what has just been stated. The alternating current flowing in a circuit is equal to the pressure divided by the opposition to the flow of the current. The total opposition or the apparent resistance offered to the flow of an alternating current by a circuit possessing inductance or electrostatic capacity, or both. in addition to the electrical resistance, is called its **impedance.** The total opposition is made up of two components, the electric resistance and the opposition due to inductance or to capacity, or to both. That part of the opposition due to other than the electrical resistance is called the **reactance.**

19. Fundamental Law of Alternating Currents. The fundamental law governing the flow of alternating currents in circuits may be briefly stated as follows:

Law.—*The current flowing in a circuit is equal to the alternating electromotive force divided by the impedance.*

This law can be put into the following very simple mathematical formula:

$$\text{Alternating current} = \frac{\text{impressed electromotive force}}{\text{impedance}}$$

20. Effect of Resistance.—Resistance is that property of a circuit that tends to obstruct the passage of a current. The effect of resistance on direct currents is such that the relation between the values of the current, electromotive force, and resistance is defined by Ohm's law, which may be stated as follows: The current, in amperes, is equal to the electromotive force, in volts, divided by the resistance of the circuit, in ohms. The effect of resistance, when not modified by any other properties of the circuit, such, for instance, as self-induction or capacity, is the same for alternating and rapidly fluctuating currents as for direct currents. Its only effect is to diminish the amplitude of the current wave. This diminution in amplitude is, under these circumstances, in exact accordance with Ohm's law.

21. Effect of Inductance.—A retardation of the current by electromagnetic inertia or inductance occurs when the current changes in value, and it therefore exercises a marked influence on the ever-changing alternating current. Faraday showed that the value of the changing current was retarded, that is, lagged behind the value that a uniform current in the same circuit would attain. The amount of the lag depends on the electromagnetic character of the circuit. Thus, a straight wire causes less retardation or lag than the same wire wound on a helix, because the helix increases the magnetic effect. Inserting an iron core into the helix may increase the retardation enormously, because the presence of the iron again increases the magnetic effect.

The electrical resistance of a wire composing a circuit depends, as is well known, on the material and temperature of the wire and on its length and cross-section; it is not affected by the flow of current, provided the temperature is not affected thereby. The inductive resistance is dependent on the *inductance* (i. e., the electromagnetic condition of the wire) and the frequency

of the alternating current. The effect of the ***inductance*** is to retard the rise and fall of the current so that it attains its maximum later than the maximum of the alternating pressure that sets it up; and it also increases the apparent resistance to the flow of the alternating current in the circuit. Thus, if one curve *M*, Fig. 9, represents the alternating current that flows in a circuit supposed to contain no inductance, another *N*

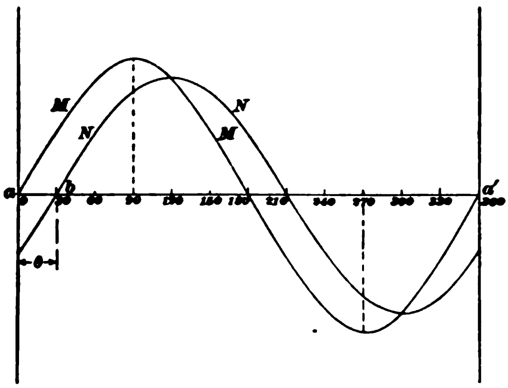


FIG. 9

can be taken to represent the current that flows when there is inductance. This latter curve *N* is retarded with respect to the former *M* and reaches a smaller maximum value.

In this figure, the distance θ (a Greek letter, pronounced *the'ta*), from *a* to *b*, expressed in degrees, is called the angle of lag θ. For $a\,a'$ represents one complete period, that is, 360°; consequently, each $\frac{1}{360}$ part of the distance $a\,a'$ is equivalent to 1°. In this case, the curve *N* lags 30° behind the curve *M*.

22. In the case of a circuit that possesses inductance and resistance, the total opposition or impedance is made up of two components, one the electrical resistance and the other the opposition to inductance, called the **inductive reactance.** The law for calculating the current in a circuit possessing only inductance and resistance is expressed as follows:

$$\text{Alternating current} = \frac{\text{impressed electromotive force}}{\sqrt{(\text{resistance})^2 + (\text{inductive reactance})^2}}$$

The impedance of a circuit possessing only resistance and inductance for a simple sine-wave current is expressed by the following formula:

$$\text{Impedance} = \sqrt{R^2 + (2\,\pi\,n\,L)^2}, \qquad (1)$$

in which R = simple resistance of circuit, in ohms;
$\pi = 3.1416$;
n = number of complete periods per second, or the frequency;
L = coefficient of self-induction, now generally called simply inductance, in henrys.

The term $2\,\pi\,n\,L$ is the inductive reactance.

If E is the impressed electromotive force and I the alternating current, the current is given by the formula

$$I = \frac{E}{\sqrt{R^2 + (2\,\pi\,n\,L)^2}} \qquad (2)$$

NOTE.—The derivation of the formula for the impedance of circuits cannot well be given here and is not essential to the proper understanding of the subject. It can be found in most complete treatises on alternating currents.

EXAMPLE.—Suppose a circuit has a resistance R of .4 ohm, an inductance L of .001 henry, and an impressed electromotive force E of 1 volt; what will be the current when the frequency n is 60 periods per second?

SOLUTION.—By formula 2, the current is

$$\frac{1}{\sqrt{(.4)^2 + (2 \times 3.1416 \times 60 \times .001)^2}} = 1.818 \text{ amperes. Ans.}$$

23. From formula **2**, it is evident that a given circuit possessing inductance reduces currents of high frequency more than those of low frequency; for the larger the value of n in the formula, the smaller will be the value of the current I. Furthermore, the larger R or L, the smaller will be I for a given frequency n.

24. Effect of Capacity.—A condenser placed across a circuit produces an effect opposite in direction to that produced by inductance. It is known that the value of the changing current in a circuit containing a condenser tends to occur earlier, or to lead the value that it would attain if the opposition to its flow consisted only of simple electrical resistance. When, in addition to resistance, a circuit possesses only capacity, an alternating current will be reduced in amplitude or strength

and will also lead the impressed electromotive force. Where there is only resistance and capacity,

$$\text{Alternating current} = \frac{\text{impressed electromotive force}}{\sqrt{(\text{resistance})^2 + (\text{capacity reactance})^2}}$$

The impedance of a circuit possessing only resistance and capacity is expressed, for a simple sine-wave current, by the formula

$$\text{Impedance} = \sqrt{R^2 + \left(\frac{1}{2\,\pi\,n\,C}\right)^2}, \qquad (1)$$

in which C = electrostatic capacity, in farads, and the other letters having their usual meaning. Then the current is given by the expression

$$I = \frac{E}{\sqrt{R^2 + \left(\frac{1}{2\,\pi\,n\,C}\right)^2}} \qquad (2)$$

25. From formula **1,** Art. **24,** it is evident that for a given circuit, the impedance is smaller the greater the frequency n of the alternating current, and from formula **2,** that the current increases in strength as the frequency increases. Furthermore, the greater the capacity, the smaller will be the impedance and the greater the current for a given frequency and resistance. These formulas for capacity apply to circuits in which the condensers are in series with the line and other apparatus. Distributed capacity, which cannot be treated in so simple a manner, produces effects that will be considered later.

26. Effect of Combined Resistance, Inductance, and Capacity.—When, in addition to resistance, a circuit possesses both capacity and inductance, the impedance and the current are given by the following formulas:

$$\text{Impedance} = \sqrt{R^2 + \left(2\,\pi\,n\,L - \frac{1}{2\,\pi\,n\,C}\right)^2} \qquad (1)$$

$$I = \frac{E}{\sqrt{R^2 + \left(2\,\pi\,n\,L - \frac{1}{2\,\pi\,n\,C}\right)^2}} \qquad (2)$$

These formulas assume that the resistance, inductance, and capacity are all in series with the line and apparatus, and that the current curve is a sine curve.

27. For any given frequency of alternation, the effect of the inductance of a circuit may be neutralized by the application of a capacity of the proper value. That this is true may readily be seen from the formulas just given. From formula **2**, Art. **26**, it is quite evident that $I=\frac{E}{R}$, when $2\,\pi\,n\,L-\frac{1}{2\,\pi\,n\,C}=0$. For a given circuit having a definite inductance L and electrostatic capacity C, it is quite plain that this expression can be made equal to zero for only one particular value of the frequency n.

When, therefore, $L=\frac{1}{4\,\pi^2\,n^2\,C}$, the current follows Ohm's law and the current will not lag behind nor lead the impressed electromotive force. Thus, by properly proportioning the inductance and the capacity of a circuit, the electromotive force due to inductance may be made to neutralize the electromotive force due to capacity, thus leaving only the resistance to oppose the electromotive force in driving the current through the circuit.

28. Unfortunately, it is distributed capacity that must be neutralized in telegraph lines and cables, and to do this requires a distributed inductance. It is well known that a cable with an inductive shunt or leak at a point near its middle will transmit signals more rapidly and distinctly than one not so compensated. The method of wrapping an iron wire or ribbon around the copper conductor in order to increase the induction has been proved to be of some benefit, and in Europe there are a few under-water telephone cables constructed on this principle.

In a paper read before the American Institute of Electrical Engineers, in May, 1900, Doctor Pupin gives a method for increasing the efficiency of a cable or line for telephonic or telegraphic transmission. His method is of much practical value and is now being extensively used on telephone bare-line wires and cables, especially on underground dry-core paper cables. By inserting inductance coils of a certain calculated

value at certain definite intervals along the wire or cable, the distortion and decrease in amplitude of the electrical waves is very much reduced. The inductance coils must be carefully calculated and distributed for each cable or line, or their use may do more harm than good. Doctor Pupin's paper is too long and complex for a satisfactory abstract to be given here.

Alternating electromotive forces and currents do not necessarily vary in such a simple way as to give an exact sine curve. In fact, some are exceedingly complex. However, only those that follow the curves of sines have been considered here, for it is not practical to make calculations concerning those that follow more complex curves. For complex curves, approximate results can only be obtained by using the formulas given.

EXAMPLE.—What must be the capacity, in microfarads, of a condenser connected in series with a telephone bell having a resistance of 1,000 ohms and an inductance of 8 henrys in order to offer a minimum impedance to an alternating current having a frequency of 20 cycles per second?

SOLUTION.—The least impedance such a circuit can possess is the resistance of the coil; namely, 1,000 ohms. To get such an impedance, the capacity and inductance must neutralize each other; in other words, $2\pi n L - \frac{1}{2\pi n C}$ must equal zero. If $2\pi n L - \frac{1}{2\pi n C} = 0$,

$$C = \frac{1}{4\pi^2 n^2 L} = \frac{1}{4 \times (3.1416)^2 \times (20)^2 \times 8} = .00000792 \text{ farad}$$

or 7.92 microfarads. Ans.

29. Impedances in Series.—The reciprocal of resistance is called conductance, hence conductance $G = \frac{1}{R}$. Furthermore, the terms following the resistance in the formulas for impedances are called *reactances*. For instance, $2\pi n L$ is the inductive reactance, $\frac{1}{2\pi n C}$ the capacity (or condensive) reactance, and $2\pi n L - \frac{1}{2\pi n C}$ the combined inductive and capacity reactance.

The total impedance of a circuit containing several resistances, inductances, and capacities in series may be calculated by the formula

$$\text{Total impedance} = \sqrt{(\text{sum of resistances})^2 + (\text{sum of reactances})^2}$$

The total impedance of a circuit containing several resistances, inductances, and capacities in parallel can only be calculated by a formula involving the sines and cosines of the phase angles and is too complicated to be given here.

EXAMPLE.—What is the impedance of a circuit consisting of a coil having a resistance of 1,000 ohms and an inductance of 8 henrys, a coil having a resistance of 2,000 ohms and an inductance of 10 henrys, and a condenser of 10 microfarads connected in series with an alternating-current generator having a frequency of 20?

SOLUTION.—The sum of the resistances is $1,000+2,000=3,000$. The reactance of the first coil is $2\times3.1416\times20\times8=125.7\times8=1,006$. The reactance of the second coil is $125.7\times10=1,257$. The reactance of the condenser is $-\frac{1}{125.7\times.00001}=-\frac{1}{.001257}=-796$. Then,

$$\sqrt{(3,000)^2+(1,006+1,257-796)^2}=\sqrt{11,152,089}=3,339 \text{ ohms. Ans.}$$

DIRECT AND ALTERNATING CURRENTS IN PORTIONS OF SAME CIRCUIT

30. As condensers, inductance coils, and non-inductive resistances are used extensively in telephone systems, their action on direct and alternating currents should be understood. A coil wound, in one direction only, around an iron core, possesses inductance and hence acts as an inductive resistance, whether the iron core is part of a relay or any other electromagnetic mechanism, or is simply used to increase the inductance of the coil. Furthermore, the total opposition, called impedance, that an inductance coil offers to an alternating, or rapidly fluctuating, current increases with the resistance, number of turns, and frequency of alternation. Where the frequency is very high and the resistance very low, the resistance may be an entirely negligible part of its impedance. On the other hand, the steady direct current that will flow through the inductance coil will depend on its resistance only and will not be affected by its inductance.

31. A condenser, on account of the very high resistance of its insulating sheets, will not allow a direct current of appreciable strength to flow through it, but it is said to allow an

alternating, or rapidly fluctuating, current, such as is produced when telephoning, to flow through it. This does not mean that any current actually flows through the insulating sheets of the condenser, but rather that the plates of the condenser are charged and discharged; that is, the charges on the plates are reversed in polarity every time the potential is reversed at the condenser's terminals and the quantity of electricity on the plates changes every time the potential changes in value. Whenever there is a change in the amount or polarity of the charge on the condenser plates, some electricity must flow into one side and out of the other side of the condenser and through the circuit. In all cases just as much electricity must flow into one side as flows out of the other, that is, the positive charge on one side is always equal to the negative charge on the other side of the condenser. The opposition that a condenser offers to the flow of an alternating, or rapidly fluctuating, current decreases as its capacity and the frequency increase. In telephone circuits, it will not generally do to use too large a capacity, because the voice currents become so much distorted in form as to become indistinct, even though their strength may not be appreciably affected.

32. A non-inductive resistance offers exactly the same opposition to an alternating, or rapidly fluctuating, current as to a direct current. This opposition is equal to its resistance only; that is, the frequency has no influence on the strength of current that a non-inductive resistance will allow to flow through it. The usual manner of representing ***inductance***, ***choke***, ***retardation***, or ***impedance coils***, as they are variously called, is shown at R or R'', Fig. 10. The addition of an armature, as shown at R', makes a relay or other electromagnetic device out of it. Non-inductive resistances are represented as at r, r'.

33. The direct current from the battery B, Fig. 10, will flow through R and r, which are in parallel, then through R', r', and R'' back to the battery. The alternating current generated by the alternating-current dynamo D, or any other source of alternating currents, as the secondary winding of an ordinary telephone

induction coil, will flow most readily through $r - C - b - C' - D$. Some may flow through coils R and R' and also through $a - B - R'' - r'$. But if the frequency of the current and the inductances of the coils R, R', R'' are made sufficiently great, most of the alternating current will flow through the resistance r and most of the direct current through the coil R. By making the capacity of a condenser C large enough, practically all the alternating current, if not too low in frequency, will pass through it in preference to passing through the coil R', and all the direct current must pass through $R' - b - r' - R'' - B$. By making the inductance of the coil R'' large enough, all the alternating current may be practically excluded from the circuit $a - B - R'' - r' - b$. By making r large in resistance and R small

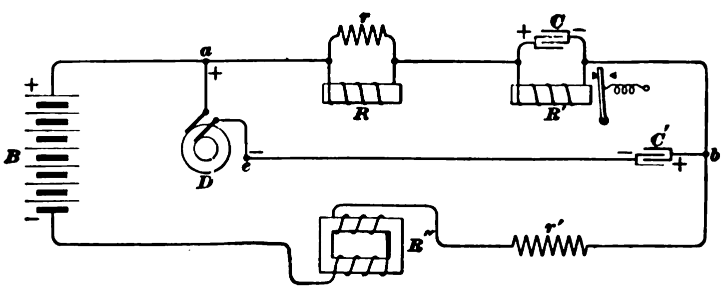


FIG. 10

in resistance, with a high inductance, practically all the direct current will be confined to R. Thus, the alternating current may be made to pass practically only through the path $a - r - C - b - C' - e - D$, and the direct current practically only through the path $a - R - R' - b - r' - R'' - B$.

When the dynamo D produces a positive potential at a and a negative potential at e, a positive charge flows to the plates of the condenser C connected toward a and a negative charge to the side of the condenser C' connected toward e; that is, a current then flows momentarily from one condenser C' through $e - D - a - r$ to the other C. The positive charge on one side of one condenser C attracts a negative charge to the other side, and the negative charge on one side of the other condenser C' attracts a positive charge on the other side of C';

hence, a current flows momentarily from one condenser C through b to the other C'. When the dynamo D reverses the polarity of a and e, the polarity of the charges and the direction of the flow of the currents are also reversed. When only a direct current is flowing, the condenser C will merely remain charged to the difference of potential across the coil R'; there will be no flow of charges in and out of it so long as there is no change in the strength of the current flowing in the coil R'.

34. A very rapidly fluctuating, or undulating, direct current may be considered as an alternating current superimposed on a direct current. As a matter of fact, the direction of such a current in a circuit does not change; but the rapid variations in its strength are readily transmitted through a non-inductive resistance or condenser, while only the steady portion of the current can readily pass through an inductive resistance. Hence, a condenser or non-inductive resistance in parallel with an inductive resistance will allow the transmission of a very rapidly fluctuating direct current through the combination, because the fluctuating portion may be considered as passing through the condenser or non-inductive resistance, and the steady portion through the inductive resistance. For such purposes, the non-inductive resistance will usually be relatively high and the inductive resistance relatively low.

THEORY OF TELEGRAPH LINES

ELECTRIC PROPERTIES OF TELEGRAPH LINES

35. Resistance.—The resistance of a telegraph circuit has two components: The resistance of all apparatus connected in the circuit, and the resistance of the line wire itself. The resistance of the line wire may be determined from tables, which are given elsewhere, or by direct measurements. A moderate amount of resistance does not in itself seriously interfere with telegraph transmission, but resistance in combination with electrostatic capacity may impose a very serious obstacle to the rapid transmission of telegraph signals.

36. Inductance.—The inductance of a telegraph circuit is almost entirely concentrated in the electromagnets connected in its circuit, and its effects are, therefore, so far as the line wire is concerned, but slight. Inductance tends to increase the apparent resistance of a circuit to alternating currents in much the same way as an increase of actual ohmic resistance would do. It has been found by experiment that, for line circuits of copper, impedance is but little more than the actual resistance.

A copper wire .104 inch in diameter has a resistance of 5.2 ohms per mile. This resistance is, of course, the actual resistance of the wire. The apparent resistance or impedance of this wire to alternating currents having a frequency even as high as 1,500 alternations per second is only about 1.4 per cent. greater, or about 5.27 ohms. So that the difference between the resistance and the impedance of a line wire due to inductance is so small as to be practically negligible.

37. Capacity.—The effects of a condenser bridged across a circuit carrying alternating currents have already been dealt

with. The condenser tends to make the current flowing in the line lead the impressed electromotive force in phase. Like inductance, it has the effect of increasing the apparent resistance of the line.

Every telephone or telegraph line may be considered as one plate of a condenser. If the circuit is a grounded one, the single line wire corresponds to one plate of the condenser, the insulation or atmosphere to the dielectric, and the earth or surrounding conductors to the other plate. If the circuit is metallic, one wire forms one plate of the condenser, the air between the two wires is the dielectric, and the other wire forms the other plate. The capacity of a line is distributed throughout its entire length, and is therefore termed **distributed capacity.** Each element or short piece of the line wire may be considered as forming one plate of a condenser,

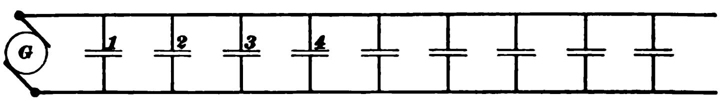


FIG. 11

the other plate of which is formed by corresponding portions of surrounding conductors and the ground. The line circuit may therefore be considered as an infinite number of small condenser plates, each acting on the currents flowing over the line.

38. The action of distributed capacity may be made more clear by considering a number of condensers bridged across a metallic circuit, as shown in Fig. 11, instead of considering each successive element of the line wire as a portion of a separate condenser. If the electromotive force of a generator *G* placed across the line circuit at one end is suddenly raised, a portion of the current sent over the line will flow into each condenser, the condenser plates keeping at the same potential as that point of the wire to which each plate is connected. Condenser *1* will receive the greatest portion of the charge, because it is subjected to the highest difference of potential. Condenser *2*, owing to the resistance of the line wires between *1*

and *2*, will be subjected to a slightly smaller difference of potential, and hence will receive a slightly smaller charge, and so on throughout the entire number, the current flowing into each condenser, of course, lessening the amount flowing into the more distant portions of the line. If the electromotive force continues long enough in that direction, a sufficient quantity of current will flow through the line to charge all the condenser plates to the full amount; but if the electromotive force continues only long enough to allow enough current to flow through the line to charge condenser *1*, the charge in each successive condenser will be less and less, and the last few condensers may receive practically no charge.

39. When it is stated that condenser *1* will be charged before condenser *2*, it must not be imagined that this slowness on the part of *2* in taking its charge is due to the speed at which an electric wave may travel along a conductor. This speed is practically equal to that of light, 186,000 miles per second, so that on the longest line obtainable, the time necessary for an electric impulse to flow through it will be almost too small to measure. This difference in the time of charging should rather be looked at in the following light: The amount of electricity, in coulombs, that will flow through a conductor depends on the number of amperes flowing and on the length of time the current continues to flow. The charge of a condenser may be measured in coulombs, 1 coulomb being that amount of electricity represented by a flow of 1 ampere for 1 second. Obviously, here is a time element that is not dependent on the actual velocity of electricity. If 1 ampere flows into a condenser for $\frac{1}{2}$ second, the charge assumed by the condenser during that time will be $\frac{1}{2}$ coulomb, and in $\frac{1}{4}$ second will be $\frac{1}{4}$ coulomb. Similarly, the amount of electric energy that can flow through a conductor depends on the strength of the current, the voltage, and the time of the flow.

40. If, at a given instant, an electromotive force in one direction is impressed on such a line as is shown in Fig. 11, there will be a rush of current into the line wire that will tend to charge the condensers. The potential at the terminals

of condenser *1* will be greater than that at the terminals of condenser *2*, that at condenser *2* will be greater than that at condenser *3*, and so on, because of the drop caused by the ohmic resistance of the line wire. Condenser *1* will therefore take the greatest charge, condenser *2* a somewhat smaller charge, and so on through each successive condenser. If condensers *1*, *2*, *3*, and *4* have the capacity to take a certain amount of charge when subjected to the potentials mentioned, and the electromotive force impressed on the line acts only long enough to allow that amount of current to flow from the source, and then reverses, these condensers *1*, *2*, *3*, and *4* will take their respective charges, and the small amount of electricity that flowed from the generator will be insufficient to charge the condensers beyond. There will therefore be no appreciable flow of current in the line wires beyond condenser *4*, for, on the reversal of the electromotive force, the charges of the various condensers will merely flow back to the source. It is not difficult to see, therefore, that a rapidly alternating electromotive force may be impressed on one end of such a line without any of the current impulses ever reaching the other end, the time between the successive impulses being insufficient to allow a sufficient quantity of electricity to flow through the line to charge all the condenser plates. If, now, each small portion of the line wire is considered as a condenser plate, the effect will be practically the same as that just illustrated.

41. The C R Law.—The foregoing shows that the length of time necessary for an impulse of current to reach the distant end of a line depends not only on the distributed capacity C of the line, but also on the resistance R of the line wire. It has been proved by extensive experiments in telegraphy that the length of time required for a current to reach its maximum strength at the distant end of the line varies directly as the product of the capacity C of the line and its resistance R. As both the capacity and the resistance are proportional to the length of the line or cable, the product $C R$, which is called the **time constant** of the line or cable, increases as the square of the length of the line or cable.

For cable work, the positive and negative poles of the battery are alternately put to the cable and to ground. At 45 words per minute, there are about 17 alternations per second. At 75 words per minute, there are about 28 alternations per second. With the same electromotive force, the amplitude of the current curve traced on the receiving paper by the siphon recorder (on a cable for which the product of the total capacity and total resistance, called the $C R$ of the cable, is 2.42) will be about 13.6 per cent. greater when there are 17 alternations per second than when there are 28 per second.

42. The essential features of a portion of an article by Mr. Willis H. Jones in The Telegraph Age, concerning the limiting value of the $C R$ law for land line wires on which quadruplex systems may be worked, are as follows:

An experimental test made in the quadruplex department of the Western Union Telegraph Company showed that a quadruplex circuit worked efficiently between New York and Buffalo, over a line having a value of 17,000 for the product $C R$. On a direct circuit between New York and Chicago, having approximately the same resistance but a $C R$ of 32,000 the quadruplex system would not work satisfactorily. The large value of $C R$ on this line is doubtless the reason for its failure to give satisfactory results with quadruplex apparatus. It would appear from these tests that the dividing line between efficient and poor quadruplex work lies somewhere between a $C R$ of 17,000 and 32,000, probably about half way; the latter suggestion, however, is but a guess.

The failure did not appear to be due to an insufficiency of current, for when the full battery, or long end, was closed and the apparatus inactive, the neutral relay gave evidence of being strongly magnetized, but the moment an attempt was made to start working, the margin of current for the neutral relay seemed to become absorbed or totally destroyed by the effects of the static charge so developed. The terms used above and applying to the quadruplex system will be clear when the quadruplex system is explained.

From this it appears that 500 miles of No. 11 or 12 B. W. G. copper wire, having a resistance of 4 to 5 ohms per mile, is about the limit for a satisfactory quadruplex circuit. Wires somewhat inferior to the above are frequently assigned to long quadruplex circuits for the want of anything better, but the great amount of care and attention they require in order to be kept workable makes it most advisable to employ duplex apparatus on such circuits.

SPEED OF SIGNALING

43. It has been shown that a perceptible time is required for a cable or line possessing distributed capacity to become fully charged or discharged in spite of the fact that electricity travels with the speed of light. It is a well-known fact that when a signal is sent through an Atlantic cable, it does not produce any effect in Newfoundland simultaneously with the depression of the key in Ireland. The distance divided by the time occupied in the transmission of the signal may be called the **velocity** with which that particular signal is transmitted. It might even be termed the velocity with which a certain quantity of electricity traverses the cable; but it is not the velocity proper to or peculiar to electricity, for under different circumstances the same quantity of electricity may traverse the same distance with different velocities.

For about $\frac{1}{5}$ second after contact is made at Ireland, no effect can be detected in Newfoundland, even by the most delicate instrument; after $\frac{2}{5}$ second the received current is about 7 per cent. of the maximum permanent current that will ultimately flow equally through all parts of the circuit. One second after the first contact is made, the current will have reached about half its final strength, and about 3 seconds after it will have attained nearly its maximum strength. During all this time, the maximum current is flowing into the cable at the sending end. The velocity with which the current travels even in this one case has therefore no definite meaning because the current does not arrive all at once, like a bullet, but grows gradually from a minimum to a maximum.

44. Fig. 12 shows the curve representing the law of increase of the received currents, which is the same on all lines. The vertical ordinates parallel to OY represent strengths of current, the maximum or permanent current flowing through the circuit after equilibrium has been reached being called 100. Hence, the vertical ordinates are really percentages of the maximum permanent current.

The horizontal distances along OX represent intervals of time, measured from the moment at which contact was first made at the sending station, and expressed in terms of an arbitrary unit a, different for different circuits, but constant for any one circuit.

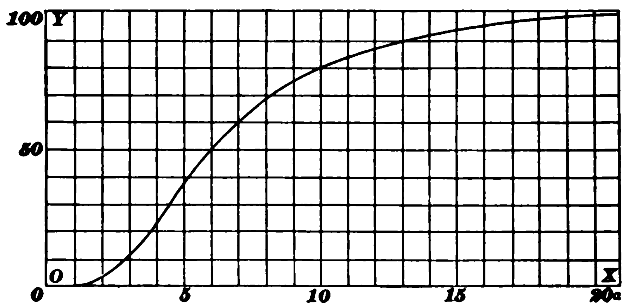


FIG. 12

For a uniform cable or line of length l, in nautical miles, a resistance of r ohms per nautical mile, and an electrostatic capacity of C microfarads per nautical mile, the value of a, in seconds, is given by the following formula:*

$$a = \frac{.02332\, c\, r\, l^2}{1{,}000{,}000} \qquad (1)$$

From this formula, it is evident that a is proportional to the square of the length l of the cable. The total electrostatic capacity C is equal to $c\,l$ and the total resistance R to $r\,l$. Hence, the $C\,R$ of the cable is $\frac{c\,r\,l^2}{1{,}000{,}000}$. The 1,000,000 is necessary to reduce microfarads to farads. Then,

$$a = .02332\, C\, R \qquad (2)$$

*The derivation of formula 1 requires the use of higher mathematics so that it cannot be given here.

For the French Atlantic cable, $c = .43$ microfarad per nautical mile, $r = 2.93$ ohms per nautical mile, and $l = 2{,}584$ nautical miles. Substituting these values in formula **1**, gives for this cable, $a = .196$ second.

TABLE I

VALUE OF VERTICAL ORDINATE FOR SUCCESSIVE MULTIPLES OF a

t in Terms of a	Strength of Current in Percentages	t in Terms of a	Strength of Current in Percentages	t in Terms of a	Strength of Current in Percentages	t in Terms of a	Strength of Current in Percentages
.40	.00000000271	1.1	.041406	3.5	18.4843	7.8	66.9600
.50	.00000051452	1.2	.089276	3.6	19.8437	8.0	68.4283
.55	.0000033639	1.3	.17048	3.7	21.2134	8.5	71.8289
.60	.000016714	1.4	.29600	3.8	22.5902	9.0	74.8717
.62	.000029252	1.5	.47634	3.9	23.9707	9.5	77.5913
.64	.000049412	1.6	.72079	4.0	25.3522	10.0	80.0200
.66	.000080817	1.7	1.0369	4.2	28.1076	10.5	82.1876
.68	.00012835	1.8	1.4303	4.4	30.8381	11.0	84.1214
.70	.00019845	1.9	1.9044	4.6	33.5290	12.0	87.3840
.72	.00029937	2.0	2.4608	4.8	36.1689	13.0	89.9775
.74	.00044152	2.1	3.0997	5.0	38.7481	14.0	92.0384
.76	.00063776	2.2	3.8185	5.2	41.2603	15.0	93.6757
.78	.00090371	2.3	4.6156	5.4	43.7003	16.0	94.9763
.80	.0012580	2.4	5.4866	5.6	46.0645	17.0	96.0095
.82	.0017227	2.5	6.4270	5.8	48.3507	18.0	96.8302
.84	.0023233	2.6	7.4316	6.0	50.5577	19.0	97.4822
.86	.0030892	2.7	8.4954	6.2	52.6850	20.0	98.0000
.88	.0040536	2.8	9.6126	6.4	54.7331	21.0	98.4113
.90	.0052539	2.9	10.7780	6.6	56.7029	22.0	98.7381
.92	.0067316	3.0	11.9858	6.8	58.9502	23.0	98.9976
.94	.0085325	3.1	13.2309	7.0	60.4116	24.0	99.2038
.96	.010706	3.2	14.5080	7.2	62.1544	25.0	99.3675
.98	.013308	3.3	15.8123	7.4	63.8252		
1.00	.016394	3.4	17.1392	7.6	65.4264		

45. In terms of a, the arrival curves for the received current of all lines are identical, and the same curves shows the law according to which the current at the receiving end dies away when at the sending end the line has been put to earth. A succession of contacts with the battery and with the earth

at the sending end, each prolonged for times equal to about 25 a, will cause the received current to follow or trace the series of curves shown in Fig. 13, each curve being a complete arrival curve. Table I shows the value of the vertical ordinate corresponding to successive multiples of a, the maximum current being 100.

46. To find the strength of the current at the receiving end in percentage of the maximum permanent current at any time t after first making contact at the sending station, divide the time t in seconds by a. This will give the time

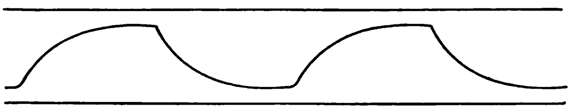


FIG. 13

in terms of a. Then the strength of the current in percentage of the maximum permanent current may be obtained from Table I, or by determining the length of the vertical ordinate at that point on the curve in Fig. 12 that corresponds to this time in terms of a.

EXAMPLE.—What will be the strength of the current at the receiving end of a cable whose CR is 4.67, .66 second after closing the key at the sending end, if the maximum permanent current that will flow is 5 milliamperes? The time given corresponds to a speed of about 40 words per minute, or about 15 alternations per second.

SOLUTION.—By formula **2**, Art. **44**, a for this cable $=4.67\times.0233=.1088$. Then the duration of one signal in terms of $a=\frac{.66}{.109}=6$. From Table I, the strength of the current in percentage of the permanent value corresponding to 6 a is about 50.56. Then the actual strength of the current at the receiving end .66 sec. after closing the key $=.5056\times5=2.528$ milliampere. Ans.

47. When the line is put to earth at the sending end before the current reaches its maximum value, the falling curve is superimposed on the ascending one and a derived curve is produced, as shown in Fig. 14. This figure shows the effect of making contact with the battery and keeping the circuit

closed until the increasing current reaches the point *b* on the ascending curve, then putting the line to earth until the decreasing current reaches the point *c* on the descending curve, and finally again putting the line in contact with the battery, causing the current to start upwards from the point *c*.

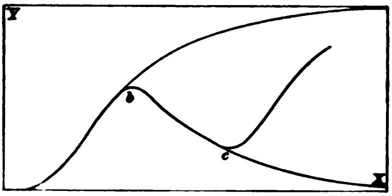


FIG. 14

A series of rises and falls may be produced in this manner that grow smaller and smaller as the length of the contacts diminish, and when the alternate contacts are made short compared with *a*, no sensible variation can be detected in the current that flows from the cable at the receiving end. As the contacts are lengthened, the amplitude of variation increases. Table II gives some amplitudes due to a succession of simple dots or equal contacts with a battery and with the earth.

TABLE II

Length of a pair of contacts, in terms of *a*.	2.90	3.00	3.50	4.00	5.00	6.00	7.00	8.00	9.00	10.00
Amplitude of current in percentages of maximum	2.69	2.97	4.52	6.31	10.42	14.85	19.67	24.42	29.11	33.68

NOTE.—If the reader desires to go further into the theory of signaling and to know how the foregoing tables and formulas were calculated, he is referred to a paper on this subject by Sir William Thomson in the Philosophical Magazine for February, 1856. Professor Fleming experimentally verified the theoretical results of Sir William Thomson and published them in the Philosophical Transactions for 1862. There is also an important paper on the subject in the Philosophical Magazine for June, 1865.

48. When a source of electromotive force is connected, at the sending station, through a key to a line, the current at the receiving end increases from zero to its maximum value more gradually than at the sending end. In the case of a submarine cable possessing considerable capacity and resistance, the current at the receiving end increases gradually from zero

along the curve shown in Fig. 12. The same kind of a curve shows the rate at which the current at the receiving end dies away when the line has been connected to earth at the sending end after the current has reached its maximum value at the receiving end. If the line is connected to earth at the sending end soon enough, the current at the receiving end may be made to start, decreasing in strength before it reaches the maximum value that it would otherwise attain. Similarly, if the circuit is closed at the sending end soon enough again, the current at the receiving end may be made to start, increasing in strength before it has had time to fall to zero. In a similar manner, there may be produced at the receiving end a series of rises and falls that grow smaller and smaller as the length of the contacts diminish, and when the alternate contacts are made short enough, no visible variation can be detected in the current at the receiving end.

49. Influence of ***a*** **on Speed of Signaling Through Cable.**—If it were necessary for the current at the receiving end of a submarine cable to reach a large fraction of its maximum value before a signal could be detected, as on land lines, submarine telegraphy would be exceedingly slow. On the French cable, from 15 to 17 words a minute can be sent. The Mackay-Bennett cable, laid in 1894 and having a $C R$ of 4.671, has a speed of 40 words a minute, and the Anglo-American cable, also laid in 1894 and having a $C R$ of 2.47, has a speed of 47 words a minute. Making allowance for the difference in the $C R$ of the two cables, it has been calculated that the speed on the Mackay-Bennett is theoretically 63 per cent. greater than on the other. This difference in speed is undoubtedly due largely to the different terminal arrangement and apparatus used by the two companies. At 15 words a minute, the duration of a dot is about .27 second or 1.28 a on the French cable. Many of the dots must produce no more variation in the strength of the received current than is equivalent to $\frac{1}{1000}$ of the maximum permanent value, and the effect of a dot probably depends on the 20 or 30 preceding signals, so that even very regular sending produces irregular results at the receiving end.

Such signals cannot be detected by an ordinary relay, but require an instrument that can detect and show every change in the strength of the current. For this purpose, a delicate receiving instrument, such as a Thomson reflecting or D'Arsonval galvanometer, has been used. The Thomson galvanometer causes a spot of light to wander over a scale and the D'Arsonval galvanometer (an essential part of the siphon recorder) causes a wavy ink line to be made on a moving paper ribbon; each instrument indicates every change in the strength of the arriving current. When the Thomson galvanometer is used, the first dot will cause the spot of light to almost cross the scale and the second moves it a little farther, but the third or fourth hardly causes a perceptible motion. The operator, however, knows by experience that each of the four different effects indicates a simple dot, each sent by the operator at the other end in a precisely similar manner. The speed of signaling, with the same receiving and transmitting instruments, will be inversely proportional to the product $C R$ for the cable on which they are used. The speed of signaling on any cable will, however, differ greatly according to the kind and arrangement of the transmitting and receiving instruments employed.

50. Influence of *a* on Speed of Signaling Through Land Lines.—Signals sent on land lines last such a long time compared to the very small value of a for such lines that, in all ordinary cases the current rises practically to its maximum value and falls to zero for each dot. A certain land line has a value of .00126 second for a. Now, this value is so small that even with 20 a for each contact with the earth (the Morse open-circuit system is here referred to) and 40 a for each dot, the dot will only occupy about .05 second, or 20 dots can be made in a second; and for every dot the current will rise almost to its maximum and fall almost to its minimum. This will give about 80 words a minute as a speed at which the effect of what is called *retardation* will be insensible in diminishing the rise and fall of the received current.

The maximum speed of signaling on any line or cable may be defined as the maximum number of signals, letters, or

sometimes words, a minute that can be sent and accurately recognized at the receiving end of the line or cable. This limiting speed may depend on the electric properties of the circuit or on the electric and mechanical features of the receiving or transmitting devices, or on the ability of the sending or receiving operator.

51. It follows from the *CR* law, that if the length of a given kind of cable is doubled, that the speed of signaling is reduced one-quarter. By using a large conductor, thereby decreasing the resistance and increasing the capacity, the value of *CR* is decreased up to a certain value, giving the minimum value of *CR*. This critical limit or point, when the size of a submarine-cable conductor that will give the lowest *CR* is reached, is when the diameter of the conductor is to the diameter over the insulation as 1 : 1.65.

There is another advantage in keeping the resistance low for any value of *CR*. The time constant only determines the time when the current at the receiving end reaches about two-thirds of its maximum possible value after the application of an electromotive force at the sending end. Of course, the amount of current after any given time is dependent on the electromotive force applied to the sending end and the resistance of the cable. For instance, if two cables of equal *CR* are constructed, but one has a larger conductor of half the resistance of the other; then, with equal sending batteries, the one with the lower resistance will deliver twice the current at the receiving end at the end of equal times, and can, therefore, be made to work at a faster rate.

An Atlantic cable laid in 1894 had the following properties: Diameter over insulation, .466 inch; diameter of copper conductor, .202 inch; resistance per nautical mile, 1.684 ohms; capacity per nautical mile, .420 microfarad; length of cable, 1,852 nautical miles; *CR* equal to 2.41; speed of working under capacity-block duplex system about 205 letters per minute. Capacity-block duplex systems are considered in *Submarine Telegraphy*.

TELEGRAPHY

(PART 4)

THEORY OF TELEGRAPH LINES

INSULATION OF THE LINE

DISTRIBUTION OF POTENTIAL ALONG A LINE

1. When a battery is connected from the ground, through a key and relay, to a line, the ground and distant grounded end of the line are at the same potential, if the ground resistance is negligible; the line terminal of the battery and the end of the line to which this terminal is connected are also at the same potential, but this latter potential is higher or lower than the ground potential. If the negative terminal of the battery is grounded, the line is said to be at a higher potential than the ground; but if the positive terminal of the battery is grounded, the line is said to be at a lower potential than the ground. If the distant end of the line is open and the insulation is assumed to be perfect, the difference of potential between any part of the line and the ground is the same as the electromotive force of the battery, as no current then flows from the battery. But if the distant end of the line is connected to ground or there is some leakage, the difference of potential between the battery end of the line and the ground will be less than the electromotive force of the battery by the product of the current and internal resistance of the battery.

2. Line Open at One End.—A very common and good way of illustrating the potentials along a circuit is by a line whose height at any point is proportional to the potential at that point in the circuit. This method is shown in Fig. 1, where the lines *A B C* are drawn as follows: At *A*, the potential is the same as that of the ground, but at the contact between the zinc electrode and the solution of each cell, the potential rises abruptly about 1 volt, for it is positive relative to the earth, and hence a vertical line whose length represents 1 volt is drawn at this point. At the second cell there is another abrupt rise of 1 volt, or 2 volts in all, above the potential of

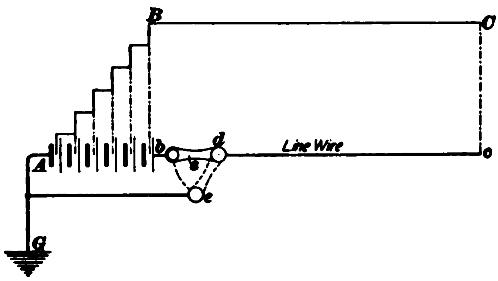


FIG. 1

the earth, and so on to the end *b* of the battery. As the distant end of the line is represented as open, and the line is perfectly insulated, there will be no change in the potential along the whole line wire. As the wire and the earth form a condenser, and the charge in a condenser is proportional to the difference of potential between the plates, the charge on the wire at any point is proportional to the vertical height of the line *B C* above the wire at that point. In this case, where the distant end is open and not grounded, and the line is perfectly insulated, the charge is uniform all along the wire.

3. If, for each unit length of the line wire a vertical line, or *ordinate*, proportional to the charge or quantity of electricity on that unit length is erected, the total charge on the whole wire will be proportional to the sum of all the ordinates so erected. As, in the case represented, the charge is uniform throughout the wire, the total charge is equal to the charge

on one unit length multiplied by the length of the line wire. Now, the length of the ordinate *b B* was made proportional to the difference of potential between the point *b* and the ground, but the charge per unit length is also proportional to this difference of potential; hence, the charge per unit length is proportional to, and may be represented by this line *b B*. Furthermore, the total charge is proportional to *b B* multiplied by the length *b c*. But this is the area of the rectangle *b B C c*, hence the total charge may be represented by the area enclosed between *B C* and the line wire *b c*.

If the battery is removed and the line instantly grounded by suddenly shifting the switch *s* so as to connect *d* with *e* instead of with *b*, the total charge flowing to earth will be proportional to the area of the rectangle *b B C c*. All of this

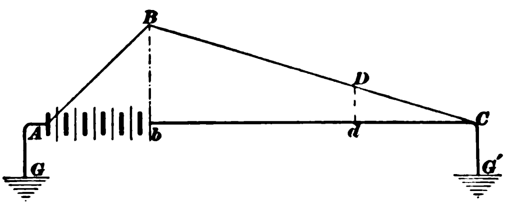


FIG. 2

charge will flow to earth through *d* and, furthermore, if the line is long and possesses much resistance and electrostatic capacity, it will require an appreciable time before the whole charge will reach the earth and leave the line neutral.

4. **Line Circuit Closed.**—Suppose, now, that the distant end is directly grounded; then the potential difference between the various points in the circuit and the ground, still assuming the line to be perfectly insulated between the two ends, will be represented by the line *A B C*, Fig. 2, and there will be a continuous flow of electricity through the circuit. Assuming that the resistance from *C* to *A* through the earth is zero, or at least entirely negligible compared to the resistance of the line, then *C* and *A* have the same potential. From *b*, which is the point having the highest potential above the earth, there is a gradual fall of potential each way to *A* and *C*; *B b*

represents the difference of potential between the point b and the earth, and, similarly, $D\,d$ represents the difference of potential between the point d and the earth. If, at the center of each unit length of the line $b\,C$, ordinates are erected from $b\,C$ to $B\,C$, each ordinate will represent the charge on that unit length of the line and the sum of all these ordinates will represent the total charge on the line. Inasmuch as the line $B\,C$ slopes uniformly, the sum of all these ordinates is equal to the average ordinate multiplied by the length of the line. Now, the average ordinate is equal to one-half the ordinate $b\,B$, plus one-half the ordinate at C; but the ordinate at C in this

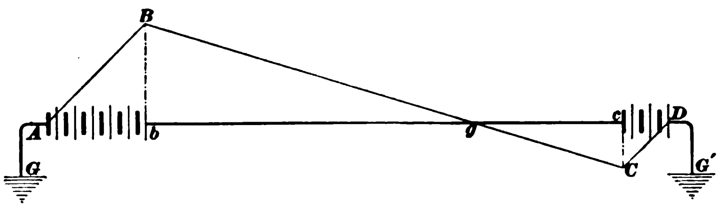


FIG. 3

case is zero, therefore the average ordinate is equal to one-half of $b\,B$. The total charge is then represented by the product of $\frac{1}{2}\,b\,B$ and $b\,C$, but this product is the area of the triangle $b\,B\,C$. Similarly, it can be shown that in any case, the total charge on a wire may be represented by the area of a figure constructed by erecting ordinates at each point along the wire, which shall represent the potential at that point, and joining their tops together by a line.

5. Battery at Each End.—In Fig. 3 is shown a general case where there are p cells at one end and q cells at the other end of the line, the two batteries being connected in series as usual. This figure, which represents the state of affairs when the circuit is closed, was constructed by erecting at b an ordinate representing the difference of potential between b and the earth when the current is flowing. This ordinate is above the line $b\,c$, because the potential at b is positive relative to the earth. But at c, the potential is negative relative to the earth, and therefore the normal $c\,C$ was drawn

downwards. If the line $b\ c$ is perfectly insulated, $B\ C$ will represent the value of the potential and charge along the wire, both in polarity and intensity.

The point g at the intersection of the lines $B\ C$ and $b\ c$ has the same potential as the earth. That there is such a point in the line is evident from the fact that the potential at one end of the line is below that of the earth, while the potential at the other end is above that of the earth, consequently, there must be some intermediate point in the line that has the same potential as the earth. The point g may be actually grounded without in any way altering the potential charges or the amount of current that will flow in the circuit. But this grounding will prevent telegraphing between b and c through this wire, because opening the circuit at b, for instance, will not stop the current in the $g\ c$ end of the line wire.

6. The total charge on the line wire when both ends are grounded is represented by the areas of the two triangles $b\ B\ g$ and $g\ C\ c$, one of which is positive and the other negative. If the line is opened instantaneously at c, the current will not stop flowing at b instantaneously, but will continue, although diminishing very rapidly, not only until all the charge on $g\ c$ has been neutralized by a charge flowing from b, but also until the whole line $b\ c$ becomes fully charged to the potential $b\ B$, as represented in Fig. 1. Evidently, then, the larger the capacity of the line, the longer is the time it requires for the current at b to fall to zero. This does not contradict the known fact that electricity travels at the speed of light, 186,000 miles per second, for the charge represents a certain number of coulombs, and the number of coulombs that will flow past a point to charge a line wire depends on the number of amperes flowing and on the length of time the current continues to flow. This time element does not depend on the velocity of electricity, as has been explained in connection with the distributed capacity of line wires.

From what has been said, it follows that a long line that has a large electrostatic capacity cannot be worked at as high a speed as a short line that has a low electrostatic capacity,

because the current does not attain its full strength as quickly when the key is closed nor fall to zero as quickly when the key is opened. Furthermore, the better the line is insulated, the slower does it work. For when the line is not perfectly insulated, the charges, when the keys are opened and closed, can redistribute themselves more quickly, because they can flow, not only over the line wire, but also through the leakage paths. Hence, a poorly insulated line, due to poor construction or to very wet weather, may work faster, if it will work at all, than a perfectly insulated line.

7. Line Not Perfectly Insulated.—In the case of a line supported on glass insulators and open at the distant end,

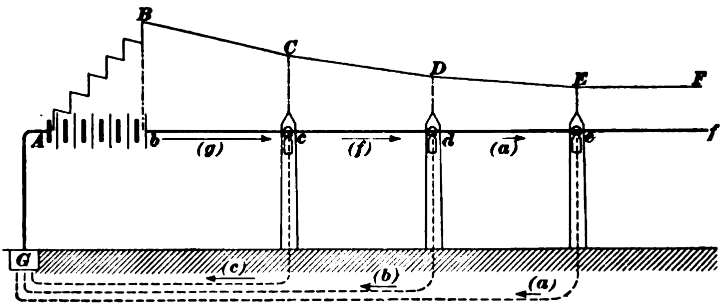


Fig. 4

suppose that each insulator has a resistance of at least 4 megohms, so that at each pole there will be a leakage of current to the ground. The escaping current will be equal to the difference of potential between the line at that point and the earth divided by the sum of the insulator and pole resistance. While the escaping current at each pole is very small, on a line 100 miles long and having 40 poles per mile, the insulation resistance at each pole being 4 megohms, the resistance of the line wire 10 ohms per mile, and the battery all at one end, the total leakage will amount to about 35 per cent. of the total current. All supports for a telegraph line form by-paths through which a part of the current flows, thus reducing the strength of the current that reaches the distant end of the line.

Such a condition of affairs is represented in Fig. 4. With the distant end of the line open, the current flowing from d to e is the amount that leaks away to earth at or to the right of e. This current causes a slight fall in potential from d to e, which is represented by the slope of the line $D E$. As the potential is slightly higher at d than at e, there will be slightly more current escaping at d than at e. The total current flowing in the section $c d$ is equal to the sum of the currents that leak to earth at d and e; hence, the fall in potential is greater from c to d than from d to e and is represented by giving the line $C D$ a greater slope than $D E$. Similarly, a greater current will escape at c than at d and the fall in potential from b to c will be greater than from c to d. There is also a fall in potential in each cell equal to the product of the internal resistance of the cell and the current, thus lowering the effective or useful pressure of each cell by that amount. The broken line $A B$ has been drawn to represent this.

8. Insulation Resistance of Line.—The total resistance from the battery terminal b by way of all the leakage paths to the ground, when the line is open at the distant end, is called the **insulation resistance of the line.** This resistance may also be defined as the degree to which the line is insulated from the ground and all other conductors. It can be readily measured by suitable methods, and may be calculated approximately step by step as follows:

Suppose that the poles are uniformly spaced and that the resistance s between the line wire and the earth at each pole is equal. Let r be the resistance of the line wire between two consecutive poles. Then, starting at e, the resistance to earth is s ohms. From d it is $s+r$ ohms, and, including d, it is, from the law for parallel resistances, $\frac{(s+r)s}{2s+r}$. Similarly, from c it is $\frac{(s+r)s}{2s+r}+r$, and, including c, it is $\frac{\left[\frac{(s+r)s}{2s+r}+r\right]s}{\frac{(s+r)s}{2s+r}+r+s}$.

In this way, the resistance may be calculated for any number of poles. However, the expression soon becomes very complex, and to carry it through will be rather laborious.

9. Even if the insulation resistance at each pole is very high, it is evident that the sum of all the currents leaking away at all the supports may be considerable if the line is long enough, and consequently only a fraction of the total current will be useful. On the 100-mile line cited in Art. **7**, only about 65 per cent. of the total current will reach the distant end of the line; hence, closing the key at the battery office increases the current at the distant office relay from zero to only 65 per cent. of the total current flowing from the battery. Opening the distant key does not reduce the current at the battery office to zero but to a strength somewhat greater than 35 per cent. of the total current. It is somewhat greater than 35 per cent. when the distant key is open, because the current flowing is less and the product $I R$, that is, the fall or drop in potential along the line, is less, and therefore the potential at each support is somewhat greater, causing a somewhat greater leakage at each support.

The lower the insulation resistance at each support, the lower will be the total resistance of the circuit and the larger the current. Thus, during wet weather the total current in a given line increases; but, with the battery all at one end, the current at the distant end is less, and, with equal batteries at the two ends, the current near the middle of the line is less than in dry weather. Furthermore, the margin or change in current strength at any station, which represents the working efficiency of the line, may be very much diminished in wet weather, especially on a long line.

10. Suppose that a long and a short line have equal line resistance (the wire larger, of course, on the long line) and that the insulation resistance at each pole is equal. In good weather, a quadruplex set may work satisfactorily on both lines, but in rainy weather it may be impossible to work the quadruplex on the long line, a duplex being used instead, but it may be worked on the short line.

This failure to work the quadruplex is due to the fact that enough increase or decrease in the current cannot be produced to work the neutral relay on account of the excessive leakage. Although the line resistance is no greater on the long line, there are so many more points of escape that the ratio of the conductivity of the line wire to the conductivity of the leakage paths is less than on the short line, and when it rains, this ratio may decrease enormously. That is, the long line is much less efficient in wet weather, and therefore the effective current is much less, although the total current may be much greater. If the ratio between the resistance of the insulation and the resistance of the line becomes too low, the line will not work satisfactorily, although the trouble from static charging and discharging may be much less.

11. Insulation.—If the resistance measured through the insulating materials from the line wire to the ground, or to other conductors, is very high, the insulation is said to be good; if very low, it is said to be poor. A properly constructed aerial telegraph line should, in dry weather, have an insulating resistance of from 2,500 to 3,000 megohms per mile. This means that the resistance of all the leakage paths from a line wire (not purposely grounded) to other conductors and to the ground measures from 2,500 to 3,000 megohms for 1 mile of wire. In wet weather, the insulation resistance may fall to 100,000 ohms per mile or even less. Prescott says that a line 300 miles in length of No. 4 B. W. G. iron wire works well with an insulation resistance of 200,000 ohms per mile. The advantages to be obtained by very high insulation on long lines are in a measure offset by the fact that a certain amount of leakage tends to reduce the condenser action between the line and the ground by allowing the static charges to leak across, and thus prevent, in some measure, the injurious effects of capacity on the speed of transmission of telegraph signals.

WORKING EFFICIENCY OF LINE

12. By the **working efficiency** of a telegraph line is meant the variation of the strength of the current at any station when the key at another station is alternately opened and closed. The working efficiency depends on the ratio between the resistance of the line (including all relays) and the insulation resistance. This working efficiency can be increased by decreasing the resistance of the line wire and the relays, or by increasing the resistance of the insulating supports, or by both methods. The resistance of the line may be reduced by using a larger wire or, better still, by using a wire made of better conducting material, for instance, by replacing an iron wire by a copper wire. The resistance of the line circuit may also be decreased by using lower resistance relays. The insulation resistance may be increased by using a higher resistance insulator or by using fewer poles per mile, or both. Less than 20 poles should not be used, and better construction requires from 30 to 40 per mile. The number of poles per mile will depend on the number and size of wires on the poles and the character of the country through which the line is run. In northern climates, where snow, sleet, and wind are common, more poles per mile are required than in southern localities.

13. Let n be the number of poles per mile, l the length of the line in miles, r the resistance of the line wire between two adjacent poles, that is, the resistance of $\frac{1}{n}$ mile of the wire, and s the resistance of one insulating support from the wire to the ground. As the insulator resistances are all in parallel, the insulation resistance per mile is evidently $\frac{s}{n}$ and the line resistance per mile is $r\,n$, from which is obtained $\frac{r\,n}{\frac{s}{n}}$ or $n^2\left(\frac{r}{s}\right)$, as the ratio on which the working efficiency of the

line per mile depends. Then, the ratio on which the working efficiency of the whole line depends is

$$\text{Ratio} = l^2 n^2 \left(\frac{r}{s}\right) \qquad (1)$$

There are usually a number of relays in the line, therefore to get the total ratio on which the working efficiency of a telegraph circuit depends, the resistance of the relays must be considered. Let R be the total resistance of all the relays in one line; where the relays, as usual, are all of equal resistance, R will be equal to the resistance of one relay multiplied by the number of relays. Then, the ratio on which the working efficiency of the circuit depends equals

$$\text{Ratio} = \frac{n\,l\,(r\,n\,l + R)}{s} \qquad (2)$$

14. If the line resistance ($n\,r$) is 8.56 ohms per mile (about a No. 12 B. & S. G. hard-drawn copper wire) and there are 35 supports per mile, each of which has an insulation resistance of 25 megohms, $n^2 \left(\frac{r}{s}\right) = 35 \times 8.56 \times \frac{1}{25{,}000{,}000} = \frac{1}{83{,}450}$ as the ratio on which the working efficiency per mile depends. In the United States, $\frac{1}{10{,}000}$ is probably as good a value for $n^2 \left(\frac{r}{s}\right)$ as can be relied on during a rain for the most carefully constructed glass-insulated line, and this figure is a fair representative value for the actual condition of lines.

Mr. Varley, the famous telegraph engineer, considered that no line was well insulated if the ratio of the line resistance per mile to the insulation resistance per mile, that is, $n^2 \left(\frac{r}{s}\right)$, was greater than $\frac{1}{80{,}000}$.

15. Percentage of Total Current Received at Distant End.—When the resistance r of the line between every two poles is constant, and the insulation resistance at each pole

is also constant, the ratio P of the total current sent into the line to the current received at the farther end, when the battery is all at one end, or to the current at the middle, when the battery is equally divided between the two end stations, may be determined as follows: Let I be the total current sent into the line and I_1 the current received at the distant end when the battery is all at the home end, n the number of poles per mile, l the length of the line in miles, r the resistance of the line wire between two adjacent poles, that is, the resistance of $\frac{1}{n}$ mile of the wire, and s the resistance of one insulating support.

$$P = \frac{I_1}{I} = \frac{2}{w + \frac{1}{w}} \qquad (1)$$

and

$$w = 2.718^{nl\sqrt{\frac{r}{s}}} \qquad (2)$$

NOTE.—Formula 1 is based on a similar formula published by Jenkin in his "Electricity and Magnetism," but its derivation is not given and cannot be given here. Unless $nl\sqrt{\frac{r}{s}}$ comes out an integer or a simple fraction, an exact solution for w requires the use of logarithms. However, an approximate solution that will usually answer the purpose can often be made without the use of logarithms.

Where an equal number of cells are used at each end, formula 1 gives the percentage of the total current that flows through a point midway between the two end offices, and l in that case is half the length of the line. Where the battery is not all at one end, it is some point between the two ends that has the same potential as the earth and through which the least current is flowing.

16. Efficiency of a Cable.—On submarine and underground circuits, the insulation depends entirely on the resistance of the gutta-percha or other insulating covering that opposes the flow of current from the conductor to the water or ground. Leakage from submarine telegraph cables is extremely small, indeed, owing to the high and perfect

insulating qualities of the gutta-percha covering. Formula 1 is applicable to cables, in which case $\sqrt{\dfrac{r\,n}{\frac{s}{n}}}$ is the square root of the ratio of the resistance per mile of the conductor to the insulation resistance per mile of the covering. If the insulation resistance of a cable is 1,000 megohms per mile, then $\frac{s}{n} = 1{,}000{,}000{,}000$.

EXAMPLE 1.—What percentage of the total current will reach the distant office in the following line circuit: The line is 200 miles long, battery all at one end, 40 poles per mile, resistance of each insulating support 4 megohms, and the resistance of the iron line wire 10 ohms per mile.

SOLUTION.— $r = 10 \div 40 = \frac{1}{4}$, $s = 4{,}000{,}000$, $n\,l = 200 \times 40 = 8{,}000$.

Hence, $$w = 2.718^{8{,}000\sqrt{\frac{1}{4} \times \frac{1}{4{,}000{,}000}}} = 2.718^2 = 7.388$$

and $$P = \frac{I_1}{I} = \frac{2}{7.388 + \frac{1}{7.388}} = .266$$

Hence, only 26.6 per cent. of the total current reaches the distant end. Ans.

EXAMPLE 2.—Suppose an iron wire having twice the cross-section of that used in the preceding example, or a copper wire of such size that the resistance per mile is reduced to 4.44 ohms is taken; what will be the percentage of the total current reaching the distant end?

SOLUTION.— $r = 4.44 \div 40 = \frac{1}{9}$, $s = 4{,}000{,}000$, and $n\,l = 200 \times 40$; hence,

$$w = 2.718^{8{,}000\sqrt{\frac{1}{9} \times \frac{1}{4{,}000{,}000}}} = \sqrt[3]{2.718^4} = 3.793$$

and $$P = \frac{I_1}{I} = \frac{2}{3.793 + \frac{1}{3.793}} = .493$$

or 49.3 per cent. of the total current reaches the distant end. Ans.

EXAMPLE 3.—Instead of increasing the conductivity of the line wire, the insulation resistance may be increased by spacing the poles a little farther apart or by using better insulators. If 9-megohm insulators are used instead of 4, what will be the percentage of the total current that will reach the distant end of the line in example 1?

SOLUTION.— $r = 10 \div 40 = \frac{1}{4}$, $s = 9{,}000{,}000$, and $n\,l = 8{,}000$. Then, $w = 2.718^{8{,}000\sqrt{\frac{1}{4 \times 9{,}000{,}000}}} = 3.793$, and hence $P = 49.3$ per cent., as in example 2. Ans.

17. Reducing Resistance of Relays.—The working efficiency of a circuit may be increased by decreasing the resistance of the relays; this is especially true on railway-telegraph lines which sometimes contain as many as 30 to 40 relays in one circuit. It has been customary on railway lines to use 150-ohm relays, but by connecting the two coils of such a relay in parallel, as shown in Fig. 5, instead of in series, the resistance may be reduced to 37.5 ohms, though it will require double the former current in the line to get the same current in each coil, and therefore the same number of ampere-turns as before. Instead of one path for the current, as in a 150-ohm relay, there are now two. The current is assumed to enter at the binding post A, where it divides, one-half passing through coil *1* and the other half through coil *2*, reuniting at the binding post B. In changing a 150-ohm relay to a 37.5-ohm relay in this manner, care must be taken to so connect the coils that their magnetizing forces do not oppose each other.

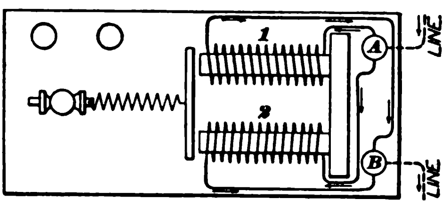


FIG. 5

18. In Table I are shown the results obtained by connecting, in this manner, thirty-six relays on a line 160 miles in length. By means of this data, most of which is taken from an actual line, the results of equipping the same line with 150- or 37.5-ohm relays may be compared. The internal resistance and electromotive force per cell is taken as 3 ohms and 1 volt, respectively.

19. A 150-Ohm Relay Equipment.—Table I shows that with 150-ohm relays the total energy expended in the line is 3.1 watts, and in the relays, 4.86 watts; the total in the line

and relays, 7.96 watts. Probably half the total energy is generally lost through leakage, therefore the resultant energy available to operate the distant relays is reduced correspondingly. On account of the high-resistance relays, the current

TABLE I

RESULTS OF CONNECTING RELAY COILS IN SERIES AND PARALLEL

	150-Ohm Relays Current = .03 Ampere			37.5-Ohm Relays Current = .06 Ampere		
	Ohms	Volts $=IR$	Watts $=I^2R$	Ohms	Volts $=IR$	Watts $=I^2R$
Line 160 miles	3,451	103.5	3.100	3,451	207.06	12.42
36 relays	5,400	162.0	4.860	1,350	81.00	4.86
Total for line and relay	8,851	265.5	7.960	4,801	288.10	17.28
292 cells battery	876	26.3	.789			
351 cells battery				1,053	63.10	3.79
Total for whole circuit	9,727	291.8	8.750	5,854	351.20	21.07

is readily choked or shunted off into the ground through the poor insulating supports, and little is left to get through to the distant relays. While, in case of excessive leakage, the battery usually supplies an additional quantity of current to the line, with a heavily loaded 150-ohm relay equipment, none of this additional current gets through to the distant relays; it merely supplies the losses due to leakage.

20. A 37.5-Ohm Relay Equipment.—In the 37.5-ohm relay equipment, the number of watts expended in the relays is 4.86—the same as in the 150-ohm relay equipment—and in the line, 12.42; the total number of watts in the line and relays is, therefore, 17.28. From this it will be seen that the energy expended in the line is four times greater than in the 150-ohm relay equipment, where it was only 3.1 watts. The 37.5-ohm relay equipment therefore gives energy to spare; and when wet weather comes, it is partly wasted, but owing to the

increased conductivity of the relay portion of the circuit, an ample quantity will usually get through to the distant relays. The percentage loss of current due to defective insulation is the same whether the current is large or small, only so long as the ratio of conductor resistance to the insulation resistance remains constant. Reducing the relay resistance reduces the resistance of the conducting circuit and, hence, increases the working efficiency of the line. The object of reducing the relay resistance is to improve the working efficiency of the circuit, especially during wet weather. The following example clearly shows the advantages of the low-resistance relay equipment.

EXAMPLE.—Suppose that the insulation resistance of a line equipped with 36 relays is 10,000 ohms during wet weather and that the resistance of the line wire is 3,451 ohms. (*a*) What will be the ratio on which the working efficiency of the line depends when equipped with 150-ohm relays? (*b*) What will be the ratio with 37.5-ohm relays, and what will be the gain in the ratio on which the working efficiency depends?

SOLUTION.—(*a*) The working efficiency depends on the ratio of the line and relay resistance to insulation resistance. With 150-ohm relays, this ratio (see Table I) is $8,851 \div 10,000 = .885$; and, with 37.5-ohm relays, it is $4,801 \div 10,000 = .48$. Ans.

(*b*) These values have an inverse meaning; the smaller the ratio, the higher the value of the ratio. The gain is the difference between the two ratios, or $.885 - .48 = .405$, and the percentage gain in the ratio on which the working efficiency of the 37.5-ohm equipment depends over that of the 150-ohm equipment is $.405 \div .885 = .46 = 46$ per cent. Ans.

21. If the resistance of all relays is made equal to the combined resistance of the line and battery, the watts expended in the relays should equal the watts expended in the line and battery. But even if these conditions should be fulfilled by limiting the number of 150-ohm relays in the circuit, the working margin in wet weather would not be up to what it is in the low-resistance equipment. Reducing the relay resistance therefore improves the working efficiency of the circuit in two ways: (1) By reducing the leakage losses by reducing the ratio between the resistance of the line circuit and the insulation resistance; (2) by supplying a surplus of energy so as to provide for unavoidable leakage losses and still leave

a good margin for the distant relays. The additional energy expended in the battery is an incidental and unavoidable loss. With high-resistance relays, there is little if any advantage to be gained by increasing the current, because it is choked off into the ground by reason of the high resistance of the relays. Of course the battery is now called on for double duty; it must supply each wire with 60 milliamperes of current instead of 30, as with the 150-ohm relay equipment, so that only about one-half the usual number of wires can be supplied from a given battery. The battery expense, both for installation and maintenance, is, therefore, approximately doubled.

22. Another advantage of reducing the relay resistance is that owing to the reduced resistance of the relays, the static charge and discharge of the line will take place more quickly and the relays will not act as sluggish. On a line wire that has considerable resistance, the relays act more quickly when their resistance is reduced; that is, the time-constant of the circuit is lower. The changed relation between the capacity of the line and the inductance of the low-resistance relays probably has more to do with it than anything else. The practical advantage of the lower resistance relays is shown by the fact that a number of prominent railroads changed their 150-ohm relays, by connecting the two coils in parallel, into 37.5-ohm instruments, and that the new arrangement gave better satisfaction, enabling them, in wet weather especially, to keep their lines working much better than before.

23. As a general rule, it is more economical to increase the efficiency of a line by increasing its insulation resistance rather than by increasing the conductivity of the line wire. However, this would have to be determined in every case by calculating the cost of doing it both ways. Table II, computed by Mr. Moses G. Farmer, and published in Volume V of the Telegrapher, shows very conclusively the good effects obtained by increasing the insulation resistance on long-line circuits. It gives the distance in miles to which a stated percentage of entering current will reach when the line wire has a resistance

of 18 ohms per mile and is supported on insulators of various resistances.

24. Best Position of Batteries in Circuit.—It has been shown by Mr. F. L. Pope, in The Electric Telegraph, that where the ratio of line to insulation resistance per mile is as poor as 1 to 10,000 and where there is consequently a great

TABLE II

EFFECT OF INCREASING INSULATION RESISTANCE ON LONG-LINE CIRCUITS

Per Cent. of Entering Current Received	Insulation Resistance per Insulator in Megohms Thirty Insulators per Mile							
	1	4	9	16	36	100	1,000	1,600
	Distances, in Miles, to Which the Stated Percentage of Entering Current Will Reach							
10	125	258	386	516	774	1,290	4,094	5,160
25	89	178	267	356	534	890	2,837	3,560
50	58	116	174	232	348	580	1,850	2,820
75	36	73	109	146	219	365	1,161	1,460
90	22	45	67	90	135	235	766	900

deal of leakage, a material advantage is gained by placing all the cells at the sending end instead of dividing them equally between the two end offices. On an open-circuit system, using an electromotive force of 200 volts at the sending end, the current at the receiving end varied from 0 to .055 ampere, thus giving an effective current of .055 ampere. On a closed-circuit system, with half the battery at each end, the current at the receiving end varied from .087 to .116, an effective current of only $.116-.087=.029$ ampere. However, on the closed-circuit system, in which case the battery is always in the circuit, when sending from a station that has no battery, it has been shown that the working efficiency is the same whether the cells are equally divided between the two end offices or are all concentrated in the middle of the line.

25. With a perfectly insulated line, it would evidently make no difference where the battery was placed in the circuit; but, as lines are never perfectly insulated, it is not best when it is necessary to send in both directions, except on relatively short lines, to put all the cells at one end. For, with all the cells at one end, the effective current at the office where the battery is located when the other end is sending will be less than the effective current at the other or distant end when the battery end is sending. Therefore, it is generally better to put half the total number of cells at each end. However, by concentrating all the battery at the sending end, sending in one direction may be accomplished over a line from which the leakage is unusually large, and over which it may be impossible to work satisfactorily in both directions. Enough cells must be used to force through the line a current of sufficient strength to work the relay at the distant end.

26. Effect on Signals of Position of a Fault.—When the batteries and instruments are alike at both ends, the worst position for a fault, such as contact with wet trees, is midway between the two end offices. When the partial ground or fault is nearer one end, the station nearest the fault receives the strongest signals. Where the fault is not at the middle of the line, experience has shown that the signals received at the end farthermost from the fault, where they are the weakest, may have their intensity increased by increasing the number of cells at the end nearest the fault.

RESISTANCE OF THE EARTH

METHODS OF MAKING EARTH CONNECTIONS

27. In the case of a long telegraph circuit composed of two line wires, the earth not being used as a return path, it is possible to obtain a certain current with a given battery in the circuit. But, if the earth is used as one path in place of one line wire, and good ground connections are made at

both ends by means of large plates of the same material placed in moist soil or running water, the current with the same battery will be almost doubled. Hence, as the resistance of the circuit has been reduced to about one-half its former value, the earth is shown to have but very little resistance. But if the line is short, and the line resistance small as a result, the resistance of the earth may be quite appreciable, which shows that the earth resistance is not zero and is only a negligible quantity when the resistance of the line circuit is large.

28. The resistance R of a piece of any material may be expressed by the formula

$$R = \frac{k\,l}{q},$$

in which l = length of piece;
q = sectional area, that is, area at right angles to direction of current;
k = specific resistance of material, that is, resistance of piece of material of unit length and unit sectional area.

The material of which the earth is composed has, in comparison with iron or copper, a very large specific resistance. The specific resistance of water is about forty million times that of ordinary copper, and the specific resistance of moist earth may even be greater; furthermore, the shortest distance between the two earth plates may not be much shorter than the line wire, hence l is an appreciable quantity. But as the cross-section of that part of the earth through which the current may flow is almost infinite, compared with the sectional area of the largest line wire that is ever used, although k is very large, and l quite an appreciable quantity, q is so very much larger that R is usually quite small and generally negligible compared with the resistance of a line wire of average length.

29. Causes of Earth Resistance.—Several things may cause the resistance of the earth circuit to be appreciable. In the first place, the current meets with opposition in passing

from the plates to the earth, which opposition is practically independent of the distance between the two ground plates, for it depends only on the surface area, the material of the plates, and the nature of the soil in which they are buried. As the resistance of the earth itself is usually very small, the resistance from plate to plate, if they are always buried in the same kind of soil, will be about the same for all distances, and will be practically the contact resistance between the ground and the two plates. Therefore, in the case of a long line of necessarily high resistance, the ground resistance is so small in comparison that it is negligible; but, in the case of a short line of low resistance, the resistance of the earth circuit may not be at all negligible.

30. According to a measurement made by DuMoucel, the resistance of the earth under favorable circumstances was about 108 ohms. (Experience in North America indicates a much lower resistance than this for a good earth return circuit.) A resistance of 108 ohms is equivalent to a 7-mile circuit of No. 9 B. W. G. iron wire. Hence, considering the electrical efficiency only, it would not pay to use the earth as a return circuit if the resistance of one line is less than 108 ohms. Commercial efficiency, however, is another thing. Where cost of construction and of maintenance of the second line wire must be considered, an earth return can be used profitably on a much shorter line circuit. The resistance of the ground return on a circuit of average length, or over should not exceed about 10 ohms where the intervening region is not too rocky or full of coal.

31. Causes of High Earth Resistance.—When the ground plates are placed in dry earth, and especially in a region where the soil and substrata are very much poorer conductors than usual, the earth circuit may have quite a large resistance. If the plates are too small, not only may the contact resistance between the plates and the earth be appreciable, but there may also be some polarization and chemical action between the plates and the material in which they are buried, especially if the two plates are not of the same material. If one plate

is copper and the other zinc, there will be a difference of potential of about 1 volt, and if this opposes the battery, there will be a reduction in the current on account of this opposing electromotive force. In making an ordinary measurement, this will appear as a simple but probably an annoying variable resistance in the earth circuit. Even if the plates are connected so as to help the battery, they will be eaten away, and the contact resistance will then increase enormously.

32. From long experience, it has been found that the resistance of the earth varies considerably. In a sandy soil, at about the level of the sea, Sinclair says it is almost impossible to get anything like a good ground, while with a clay soil it is almost impossible not to get a good ground. He also says that it is easy to establish an earth connection between two points 50 to 100 miles apart, but it is an altogether different matter to do so when they are only ½ mile apart.

In some regions, on account of their geological character, it is very difficult to secure a sufficiently good ground connection. In such a case, a return line wire may be advantageously used part of the way, until a locality is reached where a good ground can be obtained. Cases are on record in certain anthracite regions, and in some rocky or mountainous districts, where it was found almost impossible to make grounds that would not offer an abnormally high resistance.

MEASUREMENT OF GROUND RESISTANCE

33. Measurements to determine the resistance of the ground between two points are not very reliable, on account of the presence of polarization or chemical action, which it is quite difficult to eliminate. Moreover, in no two places will the resistance be necessarily equal, even with the same plates and the same distance between them.

34. Measurement by a Voltmeter.—The resistance between two ground plates may be measured by a voltmeter. The method here given is especially convenient when the two points between which the resistance is to be measured

are so near together that the resistance of connecting wires may be so small in comparison with the resistance of the voltmeter itself that their resistance can be entirely neglected. The only instrument required is a reliable voltmeter whose resistance is definitely known. A low-reading voltmeter, one whose maximum reading is 3 or 5 volts, will generally prove the best in making this measurement; very poor and inaccurate results will be obtained by trying to measure 1 or 2 volts, for instance, with a voltmeter reading as high as 150 volts.

Should there be electric street-railway, or trolley, currents flowing between the two plates, the plates will be at different potentials. The resistance of the connecting wires, if not small enough to be neglected, must be measured and proper corrections made for them; this may render the method rather inconvenient, but it is very seldom that the resistance of these wires need be considered. The current passing through a voltmeter, multiplied by its resistance, gives the difference of potential at the terminals of the voltmeter. But this is also given directly by the reading of the voltmeter; hence, the reading of the voltmeter, divided by its resistance, gives the current flowing through the voltmeter.

35. Suppose that it is desired to measure the resistance between two points A and B in the ground. At these points there may be ground plates, or at one point there may be the rail of an electric street railway and at the other the lead or iron armor of an underground telegraph cable, or the ground plate of a telegraph office. (1) Connect the voltmeter directly between A and B; then if a sufficiently large trolley current is flowing from one point to the other through the ground, the points A and B will be at different potentials and a small reading V on the voltmeter will probably be obtained. (2) Connect a number of cells, the total electromotive force of which must not be greater than the largest reading on the voltmeter, between the points A and B. As the voltmeter is also connected between A and B, it now gives a reading V_1, which is evidently the total difference of potential between the terminals of the battery. (3) Connect the voltmeter and the

same battery in series between the two points A and B. The voltmeter gives a reading V_2, and the current through the voltmeter in this position may be called I_2. Then, if r is the resistance of the voltmeter and x the resistance of the ground between the two points A and B, $I_2 r + I_2 x$ = difference of potential at the battery terminals $\pm$ the difference of potential between the points A and B that would be caused by the trolley current alone. The sign $\pm$ is used because the difference of potential between the points A and B that the trolley current tends to set up may be in the same direction (+) or in the opposite direction (−) to that due to the battery alone. Then, $I_2 r + I_2 x = V_1 \pm V$, but $I_2 r = V_2$ and $I_2 x = \frac{V_2 x}{r}$; hence, $V_2 + \frac{V_2 x}{r} = V_1 \pm V$. Solving this for x,

$$x = r\left(\frac{V_1 \pm V}{V_2} - 1\right) \qquad (1)$$

When there is no electric-railway or other stray current flowing between the two points A and B, then $V = 0$ and the formula reduces to

$$x = r\left(\frac{V_1}{V_2} - 1\right) \qquad (2)$$

Accurate results cannot be expected by this method if x is very small compared with r.

36. This is a very convenient and practical method, and one that is very useful also in determining how much current may be flowing from the lead or iron armor of an underground cable to the surrounding ground. From this it may be determined whether there is much danger to the lead or iron armor from electrolysis, and just where the corrosion is greatest, which occurs where the greatest current leaves the armor to go to the ground or other conductors. The corrosion may be avoided by permanently connecting, at the danger points, the lead or iron armor with the street-railway return feeders or rails by a good, stout copper wire.

This method, using formula **2**, Art. **35**, is very often employed by electric-light and power companies for measuring the

insulation resistance of their line wires, especially when the insulation resistance is not very high or when there is a partial ground on one line.

GROUND PLATES

37. Material for Ground Plates.—The best material for ground plates is copper, because it does not corrode or rust away like iron. The plates may be sheets $\frac{1}{16}$ inch thick and having a surface of 4 or 5 square feet. The joint between the wire and the plate should be a good metallic connection, preferably riveted and well soldered and covered with a moisture-proof paint, to prevent local chemical action, which causes an eating away of the metals at the joint. Ground plates may also be made of sheet zinc or heavily galvanized sheet iron, but they will not last, especially the latter, as long as copper plates. To prevent the corrosion of the wire leading to a ground plate, the wire should be coated with a good moisture-proof insulating material, such as rubber. The permanent ground wire at a terminal office should be a No. 8 copper wire.

38. Location of Ground Plates.—The best location for a ground plate is a stream of water, when one can be conveniently reached; the next is a well. A cistern is of no use for this purpose, for it is merely a tight vessel for holding water, and the contents have little or no connection with the surrounding earth. Where driven wells are used, the top of the well pipe should be scraped and the ground wire wrapped firmly around it and soldered to it if possible. This makes a perfect ground connection, but it may be very difficult or impossible to solder the wire to the pipe, especially if water is running through it. Dry earth, sand, gravel, etc. are not conductors of electricity; contact must be made with damp earth. It is not sufficient to put the ground plate a few feet in the earth, where in the summer the ground becomes dry, and in winter the earth freezes around and below it. Dry ice is an excellent insulator, and a ground plate in frozen earth is absolutely worthless.

If a ground plate must be buried in a sandy, gravelly, or rocky soil, where the moisture is not sufficient to render it a good conductor, the plate should be placed in a pit dug for the purpose and scrap tin or other waste metals or crushed coke or charcoal packed closely around it and the discharge from water or drain pipes led into the pit.

39. Ground Connections Through Water and Gas Pipes.—Water and gas pipes, on account of their extensive ramifications through the ground, make excellent contact with it, and for this reason make good terminals to which the wire running to the ground may be fastened. It is not very desirable, where there are electric-street-railway systems in the neighborhood, to make the ground connection through gas or water pipes. Water pipes used for this purpose on a short telegraph line near a trolley road have been known to become so weak as to burst inside of 2 months. The weakening was caused by electrolytic action due to the railway current returning through the pipe and the telegraph line circuit instead of through its normal path, the rails and the ground.

Fig. 6

If pipes are used, it is advisable to connect the ground wire to both the gas and water pipes. If the wires are grounded by means of a gas pipe, the connections, if possible, should be made to the pipe on the street side of the meter. For, if this is not done and the meter is not in place or is later removed, the return line will be open. Moreover, the white or red lead used in iron-pipe joints often makes the joints offer considerable resistance to the current before it can reach the ground.

40. Hydro-Ground.—In Fig. 6 is shown the so-called **hydro-ground** made of some kind of carbonized material, probably mixed with hygroscopic salts, molded into the shape shown. It is claimed that the material is hydroscopic, that is,

it attracts moisture, and therefore produces an earth contact of great conductivity and that it is inexpensive and easy to instal.

EXAMPLES

41. The following examples have been taken from examination questions given to determine the fitness of telegraph employes for advancement. They require for their solution only such information as has been given so far. To test one's ability to solve them without any assistance, each example should be worked before looking at the given solution.

EXAMPLE 1.—A line 10 miles long has 20 insulators, of 4 megohms each, per mile; what is the total insulation of the line and the insulation per mile?

SOLUTION.—The insulation resistance per mile is $4{,}000{,}000 \div 20 = 200{,}000$ ohms. The total insulation resistance is

$$\frac{4{,}000{,}000}{10 \times 20} = 20{,}000 \text{ ohms. Ans.}$$

EXAMPLE 2.—Insulation tests made from station A to station B gave 45,800 ohms, from A to C 15,600 ohms; what is the insulation resistance from B to C?

SOLUTION.—The insulation resistance from A to B is in parallel with that from B to C, hence that from A to C is the joint parallel resistance of the other two. Therefore, A to $C = \dfrac{A \text{ to } B \times B \text{ to } C}{A \text{ to } B + B \text{ to } C}$, or B to C

$$= \frac{A \text{ to } C \times A \text{ to } B}{A \text{ to } B - A \text{ to } C} = \frac{15{,}600 \times 45{,}800}{45{,}800 - 15{,}600} = 23{,}658 \text{ ohms. Ans.}$$

EXAMPLE 3.—A telegraph line between two stations 100 miles apart has a resistance of 1,500 ohms and at one end there is included in the circuit a battery of 60 volts and 200 ohms internal resistance and a relay of 500 ohms resistance; the resistance of the earth, which forms the return path, is small enough to be neglected. (*a*) What is the difference of potential across the relay? (*b*) If an earth fault, or ground, of 500 ohms resistance occurs 60 miles from the battery end, what will be the voltage across the relay?

SOLUTION.—(*a*) The current flowing in the first case is $\dfrac{E}{R} = \dfrac{60}{1{,}500 + 200 + 500}$ $= .027$ amperes. The voltage across the coil is, therefore, $.027 \times 500$ $= 13.5$ volts. Ans.

(*b*) The earth fault, or ground, of 500 ohms will be in parallel with the remaining 40 mi. of the line. 40 mi. of line wire has a resistance of $\frac{1,500 \times 40}{100} = 600$ ohms. The joint resistance of 600 and 500 ohms is $\frac{600 \times 500}{600+500} = 272.7$ ohms, say 273 ohms. The current through the 500-ohm coil is $\frac{60}{900+200+500+273} = .032$ ampere. The drop through the 500-ohm coil is now $.032 \times 500 = 16$ volts. Ans.

EXAMPLE 4.—A wire chief at station *B* located between stations *A* and *C* found the insulation resistance of a line from *B* to *A*, which are 100 miles apart, to be 5,000 ohms, and from *B* to *C*, which are 200 miles apart to be 3,000 ohms. (*a*) What is the insulation resistance from *A* to *C*? (*b*) What is the average insulation resistance per mile of the line from *A* to *C*?

SOLUTION.—(*a*) As all insulated paths are considered to be in parallel, the insulation resistance from *A* to *C* will be the joint resistance in parallel of that from *B* to *A* and from *B* to *C*. Hence, the insulation resistance from *A* to *C* is $\frac{5,000 \times 3,000}{5,000+3,000} = 1,875$ ohms. Ans.

(*b*) The total length of line is $100+200=300$ mi. The average insulation resistance per mile for the whole line is $1,875 \times 300 = 562,500$ ohms per mi. Ans.

DISTURBING CURRENTS IN LINE WIRES

CAUSES OF DISTURBING CURRENTS

42. The strange noises frequently heard in telephone instruments connected with grounded telephone lines may be due to one or more of several causes: The sudden shifting of the earth's magnetic field may induce, in the line, currents that will cause sounds in the receiver; earth currents, due to differences in potential between the ground plates at the ends of the line, may also pass through the telephone instruments, producing the same results; there may be leakage from other lines; a neighboring wire carrying fluctuating currents may have set up about itself a varying magnetic field of force, which field may embrace the telephone line under consideration and cause,

by its fluctuations, corresponding alternating currents to flow in the telephone line; and there may be a condenser action between the telephone wire and the neighboring wire by which the latter may induce fluctuating electrostatic charges on the former, which charges, in trying to flow to the ground, will produce currents capable of affecting the receivers.

Disturbing currents are similarly produced in telegraph line wires and, if intense enough, may cause the relays to chatter and even prevent the transmission of telegraph messages. Leakage currents can be eliminated by the proper insulation of the telegraph and disturbing line wires. Earth currents can usually be entirely eliminated by using another line wire, instead of the earth, as a return circuit. A pair of wires constituting one circuit is termed a *complete metallic circuit*. A complete metallic circuit will also very often eliminate electrostatic- and electromagnetic-induction troubles in telegraph-line circuits. However, to eliminate induction troubles it is sometimes necessary on telegraph lines and invariably necessary on long telephone lines to regularly transpose the position of the two wires constituting a pair. On telephone lines between towns and cities, so-called long-distance telephone lines, the transpositions to eliminate induction between neighboring telephone circuits, are usually placed about 1,300 feet apart.

On telegraph lines, transpositions are not very often required and seldom are so close together.

TRANSPOSITIONS

43. In Fig. 7, *A* represents a wire through which a current is flowing, this current may cause, either by electromagnetic or electrostatic induction, an induced current to flow in the wire *B*. If, instead of one wire *B* and an earth return, two wires and no earth return are used, the effect of both electromagnetic and electrostatic induction can be neutralized, as far as causing any current to flow in either wire, by twisting the two wires together as shown at *C*. In this case, each wire must have an insulating covering.

The same result is accomplished on bare overhead circuits by transposing the two line wires *D*—the outgoing and return conductors of one circuit—occasionally, as shown at ***m*** and ***n***. One way of making such a transposition on a pole is shown in

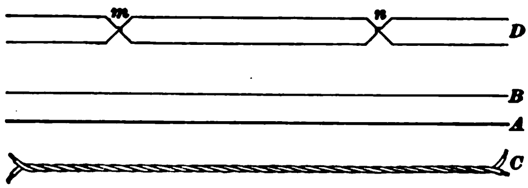


FIG. 7

Fig. 8. Insulators having two grooves, and called ***transposition insulators***, are used for this purpose. This transposition is used mostly for iron wires, in which case the joints *x* should be well soldered.

Where the joints at transpositions are made with McIntire or other sleeves, which are generally required for line circuits of hard-drawn copper wire, the transpositions are usually made as shown in Fig. 9 (*a*), where both wires are on the same side of the pole and in (*b*) where the pole comes between the wires.

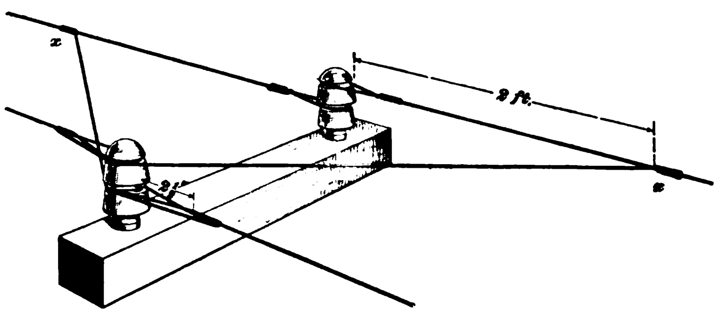


FIG. 8

Whole sleeves are used at *c* and *d*, and half sleeves at ***e***, ***f***, ***g***, ***h***, ***i***, and ***j***. In any case, the cross-over wires should either be insulated or else so bent as to avoid the possibility of crosses, the latter plan being the more common.

44. Transposition Insulator and Pin.—When transpositions are made in this manner, an insulator with two grooves around it must be used. A **transposition insulator** and its pin is shown in Fig. 10 (*a*) and (*b*), respectively. The insulator (*a*) is made in two separate pieces, each having a groove around it. The pin screws through the lower one into the upper one.

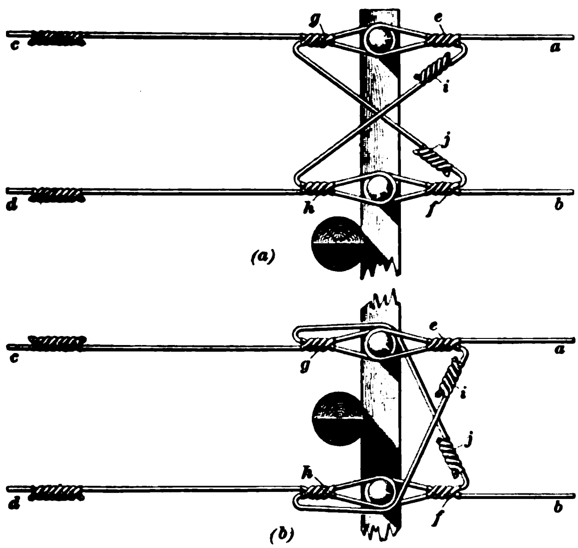


Fig. 9

This is sometimes known as the **Hibbard transposition insulator.** Transposition insulators are also made in one piece.

45. Cutting in a Transposition.—Transpositions made with sleeves are usually cut in about as follows: Cut the wires *a* and *b*, Fig. 9, on the pole side of the cross-arm 20 inches to the left of the cross-arm in this figure, slip half sleeves *e* and *f* on each wire *a* and *b* and dead-end these wires, leaving the ends projecting from the sleeves. When twisting the sleeve at a dead end hold the stationary clamp next the insulator so that the twist will be made in the long section. Then cut in 6 feet of slack wire by means of a whole sleeve on each of the

other wires *c* and *d*; slip half sleeves *g* and *h* on the slack ends; pull up the wires and dead-end them, leaving the long ends on after the dead ends have been made; connect these long ends with the opposite short ends by half sleeves *i* and *j*. Some advise using test connectors about every 5 miles in place of the half sleeves *i* and *j*. At such connectors the line circuit can be readily opened to facilitate testing. Wires *a* and *d* are dead-ended in top grooves of the insulators and *b* and *c* in the bottom

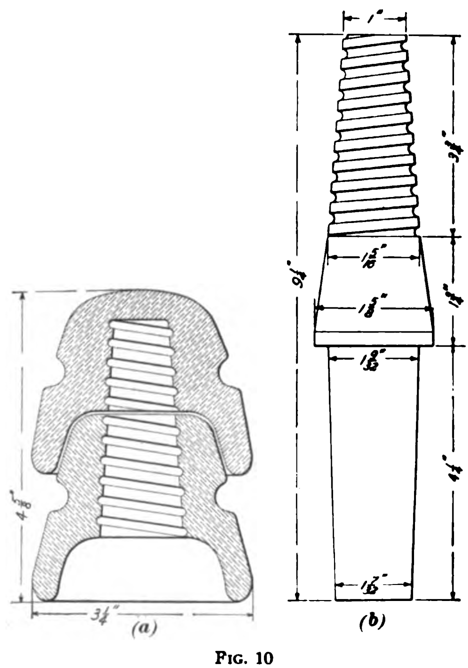


FIG. 10

grooves. The wires crossing from one side to the other should be placed in such a manner that they will not become crossed. All half sleeves are to be given one and one-half ($1\frac{1}{2}$) twists, and whole sleeves three complete twists.

When the pole wires are to be transposed, the long ends are to be brought around the insulator on the side away from the pole, so that the complete transposition will be made on the cross-arm side of the pole, as shown in Fig. 9 (*b*).

46. There is a disadvantage in connection with the method of making transpositions, just described, which is particularly apparent where telegraph and telephone service are given simultaneously on the same line. To explain this point fully, just a word must be said on the two methods of giving telegraph service on a telephone line. Telegraph service is given either by the **simplex method,** or the **composite method.** By the simplex method, both conductors of the telephone circuit are taken for the metallic side of one telegraph circuit, the earth, or another such pair of wires, being used as a return. In this case any change in the relative positions of the two conductors does not affect the proper working of the telegraph circuit, or as it is frequently termed, the **Morse circuit.** By the composite method, each conductor of the telephone circuit is used as an independent telegraph, or as it is frequently termed, a Morse, wire, so that whatever transpositions are

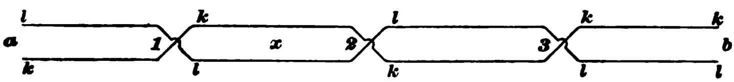


FIG. 11

cut in, the relative positions of the conductors must remain unchanged at the terminals of the line. Reference to Fig. 11 will illustrate this point. Suppose that *l* and *k* are the two conductors of a telephone line running between the stations *a* and *b* and that regular transpositions are cut in at the points *1*, *2*, and *3*. If an extra, or special, transposition is cut in at *x*, for example, the relative positions of *l* and *k* will be reversed at the terminals; and as a result, the telegraph subscriber working on *l* at *b*, will then be connected to the one working on *k* at *a*. To overcome this difficulty with the standard system of transposing, the work of transposing must be done at such a time as the telegraph service is not given, so that the line may be tested out after the work is done and the proper reversals made at *a* or *b*, to insure the proper connections before this service is resumed. Again, the cutting in of a standard transposition necessitates the opening of the line for an appreciable time. Now, when telephone service

only, is given, the service may be continued over another circuit, by mutual arrangement between the two offices during this interval. But where the wires are leased for telegraph circuits, the case is different, for the subscribers require uninterrupted service during the day, and there are usually not enough spare wires to transfer the service. So that the cutting in of special transpositions by the standard method is detrimental both with the simplex and composite systems.

47. Single-Pin Transpositions.—To overcome these difficulties, a new system of transpositions was invented by Mr. Murphy, chief of construction of the Westchester division of the New York Telephone Company. It is known as the **single-pin, or Murphy, transposition.** Old construction men, however, maintain that this system is not

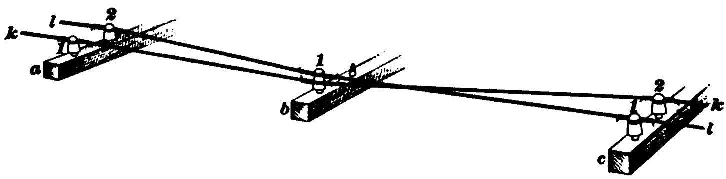


FIG. 12

new, but that it was used in the early 80's in New England. However that may be, it is claimed that it possesses the distinct advantage of avoiding the opening of the line when it is cut in on a line while it is being put up. The nature of this transposition is shown in Fig. 12. Suppose that the pole *b* is the one on which the transposition is to be made on the wires *l* and *k*, which take at pole *a* the pins *2* and *1*, respectively. A transposition insulator is placed on pin *1* at the pole *b* and the conductor *k* is tied in the lower groove at the pole *b*, while the conductor *l* is tied in the upper groove. On the next pole *c*, the conductor *k* will be tied in the usual manner to pin *2* while the conductor *l* will be tied to pin *1*. Their positions are thus reversed.

48. Construction of the Single-Pin Transposition. When the line wire is being run out on new work, this transposition can be made in most cases without cutting the wires;

enough slack is taken up to enable the wires to be shifted one pin to the right or left as the case may be. The wires on the transposition arm *b* and on the adjacent arms *a* and *c* must pull against the insulators and not on the tie-wires. On straight sections of the line, the transposition insulator should be placed on the pin farthest from the pole, that is on the outside pin. Where the pole is between the two wires to be transposed, for the sake of uniformity, the transposition insulator should always be put on the pin on the left side of the pole looking in the direction in which the pole line is considered to run, usually from the exchange.

49. When it is necessary to make the transposition on an existing line, proceed as follows: First pull up the slack wires

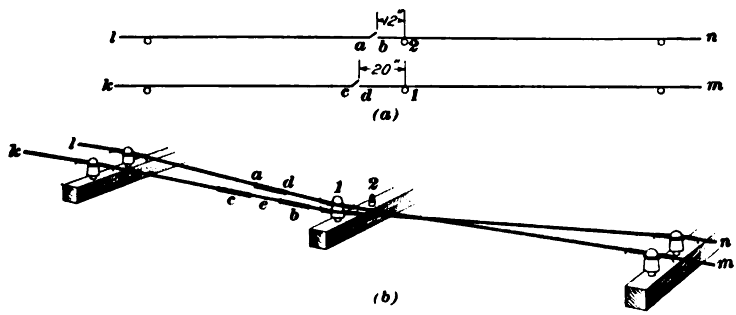


FIG. 13

in the usual manner by the aid of block and tackle and *come-alongs* or *eccentrics*, as the wire-grippping tools are called, and before cutting either wire. Then cut the wire *l* at *a b*, Fig. 13 (*a*), 12 inches from the insulator *2*, and cut the other wire *k* at *c d*, 20 inches from the pin *1* on the same side of the cross-arm as *a b*. The transposition insulator should be on the outside pin *1* or on the left-hand pin looking from the exchange when the pole is between the two wires. Bring both wires over on the outside of the transposition insulator and join one end *a* of the wire *l* to one end *d* of the wire *m* by a sleeve, as shown in view (*b*), and, by means of an extra piece of wire *e* about 30 inches long, join end *c* of the wire *k* to end *b* of the wire *n*

by the use of two sleeves as indicated. The sleeves should have the regular number of twists and each end of the tie wires should be given five full wraps around the line wire. The wire resting in the top groove should be tighter than the wire in the lower groove, in order to reduce the liability of the two wires becoming crossed.

In any system of transpositions, some companies insist, probably for the sake of uniformity and facility in tracing any particular line wire, that the same direction of spiral movement should be followed on any one pole line; for instance, the left-hand wire, looking always in the same direction along the pole line, should always go over the right-hand wire at the transpositions. This is not usually necessary, however, for the mere elimination of induction troubles.

50. Advantages and Disadvantages of Single-Pin Transposition.—Mr. F. F. Fowle says that the single-pin transposition has the comparative advantage of less first cost and simpler construction, that it can be cut in at any time, cut out, or moved several poles, at less cost and with much less work than in the case of a square, or ordinary, transposition, and that, while the single-pin transposition changes the plane of the circuit, the wire separation is greatly reduced, which is an advantage. As it requires two spans in which to make this transposition, it is possible, in case of excessive induction, to make on a given number of poles only one-half as many of the single-pin transpositions as of the ordinary square transpositions. The greatest disadvantage with this method, seems to be the fact that the two conductors being superposed, the one above the other, for a short distance on both sides of the transposition insulator, they are liable to become crossed when coated heavily with ice. The single-pin transposition is now considered the standard transposition of the American Telephone and Telegraph Company, and is being used on their long-distance lines.

51. Transposition Insulators.—It has been found practicable to neutralize the distributed capacity of line wires by inserting inductance coils in series with the line at regular

intervals. Thus there are telephone circuits of No. 8 B. W. G. hard-drawn copper wire from New York to Denver, about 2,000 miles, in which the *inductance*, or *load*, *coils*, as they are termed, are inserted every 8 miles. The difficulty with long

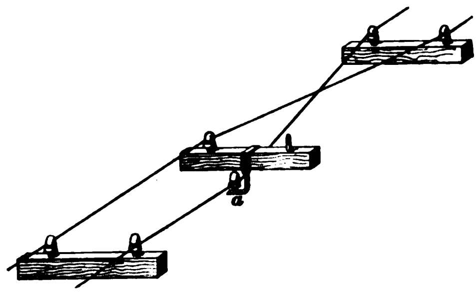


FIG. 14

loaded lines was to make them work well in wet weather. At one time some loaded lines which would be very superior in good weather, would actually be inferior in wet weather to similar unloaded lines. This difficulty was due to poor insulation, and largely to the leakage from one wire in one groove of a transposition insulator to the other wire in the other

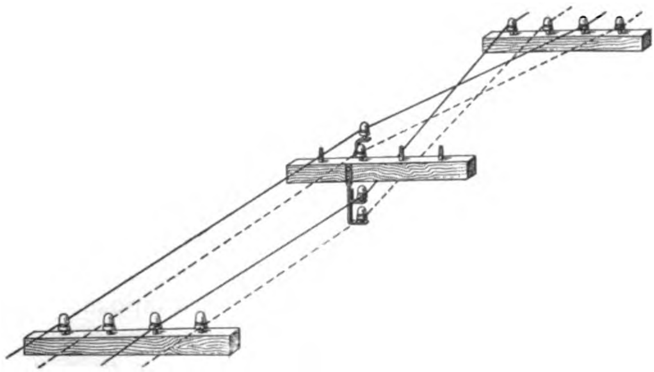


FIG. 15

groove of the same insulator when the surface of the latter was wet or damp. To overcome this trouble the transposition is made, as shown in Fig. 14, with separate double-petticoat porcelain insulators, the lower one *a* being mounted on an iron

bracket hung over the cross-arm. The insulation of such a transposition is said to be as good as at other insulator supports along the line.

52. Transposition of Phantom Circuit.—When two No. 8 B. & S. G. copper-wire telephone circuits (four conductors) are combined to form a third circuit, the latter circuit consists of both wires of one pair in parallel as one conductor and both wires of the other pair in parallel as another conductor. The two pair that would ordinarily form two entirely independent circuits are known as physical circuits; the third circuit, each side of which is formed from one pair, is known as a phantom circuit. Thus it is possible to have three telephone circuits over these four wires (two pair), without any earth circuits between New York and Denver. In order to transpose the four wires forming a phantom circuit the arrangement shown in Fig. 15 is used. An iron bracket supporting three double-petticoat porcelain insulators is used, the fourth insulator being mounted in the usual position on the pin on the cross-arm.

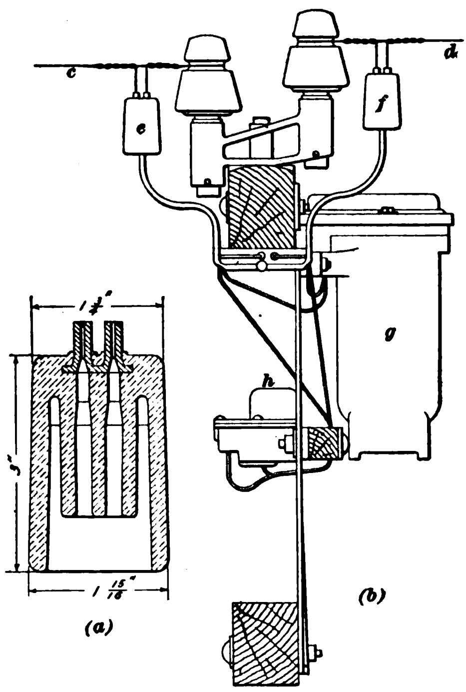


Fig. 16

53. Bridle Insulator.—Considerable leakage also occurred, especially in wet weather, where it was necessary to connect the line through bridle wires with the inductance, or

so-called load coils, and with testing stations. To improve the insulation at such points a bridle insulator is used. A cross-section through a bridle insulator is shown in Fig. 16 (*a*). In (*b*) is shown the arrangement of insulators and bridle wires that is said to have completely eliminated low insulation at bridling points. From each line wire *c* and *d* two insulated wires pass down through each bridle insulator *e* and *f*, one wire from each line goes to the load coil contained in the iron case *g* and one wire from each line goes to the lightning arrester at *h* which protects the load coil. Just below the cross-arm is a spark gap across which static charges can pass from one line wire to the other, forming a shunt path around the load coil and its protector.

TELEGRAPHY

(PART 5)

DISTURBANCES IN TELEGRAPH LINES

CAUSES OF DISTURBANCES

EARTH CURRENTS

1. Disturbances in telegraph circuits are due to the potential of the earth varying at different times and in different places from some known or unknown cause. These variations of the difference of potential between the extremities of a telegraph line cause currents, called **earth currents**, to flow in the line wire. These currents vary both in direction and strength, sometimes rapidly, sometimes slowly.

Earth currents may be due to one or more of several causes, but it is only occasionally, and during what are termed electric or magnetic storms and during auroral displays that these currents become strong enough to interfere with telegraphing. The sudden shifting of the earth's magnetic field may cause currents to flow through the line, while some have noticed that the earth currents are apparently increased at the time of the appearance of sun spots.

2. Atmospheric Disturbances.—Electrical disturbances that usually accompany aurora-borealis displays produce in line wires currents that frequently reverse in direction and are so strong as to stop all work on the telegraph lines. As might be expected, the effects of these currents are usually

§ 20

felt most on lines running east and west; that is, on lines running across the disturbance. Furthermore, the longer the lines, the greater, usually, is the disturbing effect. In Canada, in 1903, the disturbance thus caused continued for about 3 months and was so severe at times as to stop all work on east-and-west lines over 200 miles long. Twice in one week, in June, 1904, the same copper circuits could not be used for 7 to 10 hours at a time. Because of these disturbances, long copper wires that are usually duplexed are often rendered useless.

Hours before they are noticeable on other lines, auroral disturbances are usually felt on two copper wires that run from Montreal to Vancouver, with repeating stations at Fort William, 1,005 miles from Montreal, at Winnipeg; 527 miles from Fort William; and at Swift Current, 850 miles from Winnipeg; a total distance of over 3,000 miles.

3. It is frequently possible to work lines, when the aurora borealis is present, without any terminal or intermediate batteries. The lines are merely grounded at each end; but usually the potential is so changeable, even reversing its polarity frequently and usually at uncertain intervals, but sometimes reversing rather regularly, perhaps every 3 minutes, that working without batteries is merely an undesirable refuge in time of trouble. Several times messages have been sent from Fort William to Montreal and the line from Fort William to Winnipeg has been worked steadily for 35 minutes without batteries. As much as 50 milliamperes have been measured in the line from Fort William to Montreal with both ends merely grounded and more between Montreal and Winnipeg. When there is no disturbance, this line is worked nearly every night after midnight from Montreal to San Francisco. In North Dakota the voltage due entirely to the aurora varied from 185 positive to 185 negative and in one instance increased to 300 volts and produced a current of 23 milliamperes.

4. The trouble produced in telegraph lines on account of the electrical disturbances in the atmosphere or earth varies so much in different localities and times that directions suitable for one case may not apply to another; these disturbances are

usually so very irregular and erratic that no directions can be given. However, a little of the experience of those who have been through such trouble may prove useful.

When the aurora borealis appears first, the quadruplex circuits and then the duplex circuits are rendered useless. When the duplex refuses to work any longer on the usual single line wire and ground return, it may be kept working, if there is available another wire running between the same two stations, by the following method: Use the higher resistance line wire as the regular duplex line and the lower resistance line wire in place of the ground return. The duplex set will have to be balanced and usually another condenser will have to be added to the artificial line.

As the aurora increases the working of the duplex becomes light one minute and heavy a few minutes later. Another evidence of its presence is the fact, that if the distant office is asked to ground his line, the testing office is unable to tell when he does so and in a few minutes the current may reverse and the armature of the polar relay will go to the other stop. It is worse than useless to try to balance a duplex set under such varying conditions, for in 15 minutes the aurora may entirely disappear and the set would have to be balanced again; whereas, if the balance has not been altered, the duplex circuit is ready for immediate use. Balancing a line 1,000 miles long, requiring four to six condensers, requires considerable care and some time. One of the first indications of aurora on a duplex line is the unusual heating of the polar relays.

5. As the aurora becomes worse, the line must be worked simplex instead of duplex. The working of a simple Morse set on a single line can often be improved, under such conditions, by using more repeating sets in the circuit. Moreover, it is better to ground one end of the line, using a battery at the other end only, as the reversals are not then so troublesome to the operators. When the aurora is so strong as to reverse the current the relays may get so hot as to require their removal from the circuit to prevent injury to them. If a simple ground-return Morse circuit refuses to work, a complete

metallic circuit should be used, that is another wire, in place of a ground return, should be employed.

6. Disturbances Due to Trolley Roads.—Earth currents from electric railroads sometimes cause considerable trouble, because nearly all electric railroads operate on grounded circuits and use very large currents. As these currents return through the earth, the potential of the earth, for considerable areas, is frequently raised above the normal. The current, after passing from the trolley line through the car to the earth, seeks the most direct and easiest path back to the power station. If the two ground plates are at different potentials, some of the current passes up through the ground wire at one end of the telegraph line, through the instruments and line to the ground at the other end. These currents vary in strength according to the position of the car or cars on the line.

The action of trolley currents on the working of simple telegraph circuits is more or less dependent on whether the earth intervening between the rails and the ground plates of the telegraph circuit is moist enough to form a good conducting medium, and the current becomes serious or harmless according to the conductivity of the track circuit. The longer line circuits, on account of their high resistance and the distance between the two ground plates, seldom come within range of the influence of trolley currents. The shorter lines, however, are apt to suffer considerably without exciting suspicion as to the cause of the trouble, more especially in wet weather, when the effective signaling currents are weakest and the dissemination of the trolley currents through the moist earth is greatest. On some short lines it has been possible to operate by means of the trolley currents alone, the regular working batteries having been removed from the circuit.

7. Overcoming Earth Currents.—The trouble due to earth currents may be avoided by employing a complete metallic circuit, that is, using a return wire in place of the earth return, and disconnecting the wires from the ground at both the terminal offices. In this case, main-line batteries at one or both ends must be connected directly in series with the two

line wires, that is, there should be no ground anywhere on the circuit. Where this arrangement is only occasionally necessary, two line wires may be used for one circuit. This, of course, gives only one telegraph circuit in place of two.

INDUCTION DISTURBANCES

8. Induction From Other Lines.—A neighboring wire carrying fluctuating currents will set up about itself a varying magnetic field of force, which field may embrace the telegraph line under consideration, and cause, by its fluctuations, corresponding variable currents to flow in the telegraph line. Furthermore, there may be a condenser action between the telegraph wire and the neighboring wire by which the latter may induce in the former fluctuating charges that may develop into currents capable of affecting the relays.

9. Overcoming Induction.—On telegraph lines, the induction is not often serious enough to cause trouble. Where this is the case, however, the surest way to cure it is to employ a complete metallic circuit, that is, to use a return wire in place of the earth return, and place the two wires very close to each other, or twist the one about the other so as to maintain a mean average equality of distance between themselves and the disturbing wire or wires. On bare overhead circuits twisting one about the other is accomplished by properly transposing the two line wires constituting a pair. In cables it is accomplished by twisting the two insulated wires around each other. Where two wires of the same circuit are kept at the same average distance from the disturbing wire or wires, however near they may be, the influence of the disturbing circuit on each wire of the other circuit must be identically the same, both in direction and intensity; and these similar influences must therefore neutralize each other.

TELEGRAPH SYSTEMS DISTURBED BY ALTERNATING-CURRENT LINES

10. Current Required to Disturb Standard Relay. If a standard 150-ohm relay is adjusted to have a magnetic air gap of .07 inch and a length of stroke at contacts .015 inch,

and if the spring is so adjusted that the relay will attract its armature when 40 milliamperes direct current passes through it and will release its armature when the current is reduced to 30 milliamperes, then 31 milliamperes of a 25-cycle alternating current will cause the relay to chatter when the armature is on the back stop and 62 milliamperes of the same current will cause the relay to attract its armature strong enough against the front stop to start chattering of the local sounder. Twenty milliamperes of 25-cycle alternating current will cause the relay

TABLE I

IMPEDANCE OF STANDARD 150-OHM RELAY

Air Gap Inch	Impedance Ohms	25-Cycle Current When Measuring Impedance Milliamperes
.12	465	89
.11	474	88
.10	488	86
.08	515	82
.06	555	77
.05	580	74
.04	650	67
.03	725	61

to break contact on the front stop when it is added to 40 milliamperes direct current flowing through the coils. A different adjustment of gap, length of stroke, and spring tension will, of course, give quite a different set of current values. The impedance of a standard 150-ohm relay at 25 cycles is given in Table I.

NOTE.—This information on the disturbance of telegraph systems by neighboring alternating-current circuits is gathered from a paper presented in October, 1909, by J. B. Taylor, to Am. In. of E. E.

11. Eliminating Slight Disturbances to Telegraph Systems.—When telegraph relays are slightly disturbed by a neighboring alternating-current circuit, their working may be improved by one or more of the following methods: Increasing

the impedance of the line, increasing the working current, shunting apparatus with condensers or non-inductive resistance, placing short-circuited secondary winding on relays, placing neutralizing winding on relays, using back contact of relay with a reversing repeating sounder, as is used in some duplex and quadruplex local circuits.

12. By placing additional resistance and inductance in the telegraph circuit, the superimposed alternating currents will be reduced in proportion to the increase of impedance. At the same time the voltage applied to the telegraph circuits must be increased to maintain the direct current at its usual value. By using a large direct current, the percentage increase and decrease due to induced alternating currents will be less, with consequent reduction in the disturbance of the relay. Shunting the relay with a condenser or a non-inductive resistance

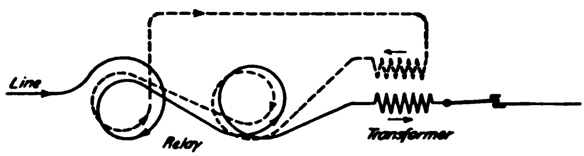


FIG. 1

diverts a portion of the alternating current from the relay winding and will help the particular relay it shunts, but it will not help the line as a whole. By placing the relay winding over a thick copper tube or on a copper spool surrounding the iron core, alternating currents, that will tend to oppose the effect of the alternating current in the winding, will be induced in the copper tube. In a second, or neutralizing, winding of a differential relay, currents in opposite direction to the alternating currents in the main winding may be introduced by means of a small transformer connected as shown in Fig. 1.

As the signaling currents in a telegraph line are variable, pulsating, or alternating, any of the foregoing choking, shunting, absorbing, or neutralizing devices will tend to make the action of the relays sluggish; and, if the frequency of the signaling currents equals or exceeds that of the induced currents, these devices will become a hindrance rather than a help.

13. Bug-Trap Remedy.—As a relay is less apt to be disturbed when the armature rests on its back contact, a disturbance may be less noticeable when the local circuit containing a repeating sounder is closed through the back contact of the relay and the repeating sounder in turn closes through its back stop the circuit containing the reading sounder. This arrangement, known as a *bug trap*, was devised by Mr. Edison in the early days of the quadruplex. It is possible to accomplish a similar result by using a flexible or spring contact on the relay so arranged as to allow a slight vibration of the relay armature without opening the local circuit.

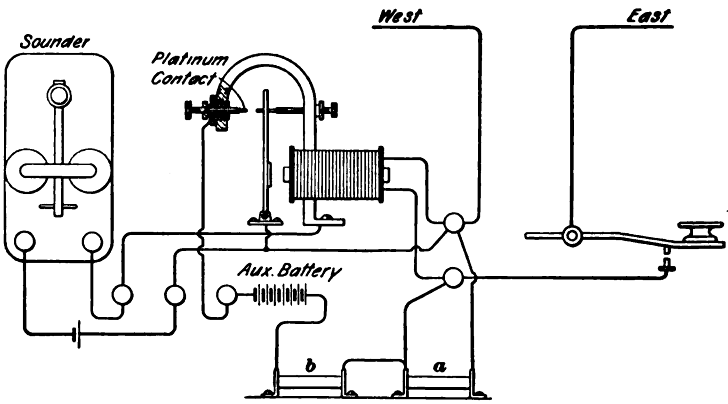


Fig. 2

14. Use of Shunts and Cells.—Mr. E. W. Applegate found that a 350- to 400-ohm coil connected in parallel with an ordinary relay would eliminate the chattering of the relay due to a 11,000-volt three-phase alternating-current circuit running parallel with the telegraph line, even when the three-phase circuit was greatly unbalanced. On account of the inductance that 400-ohm coils would add to the line circuit, he advises the use of non-inductive resistances, such as carbon rods or incandescent lamps, although neither will eliminate the relay chatter quite as effectively as a coil.

A few cells, arranged as shown in Fig. 2, Mr. Applegate says, liven up the instruments and compensate for the slight loss due

to the use of non-inductive resistance shunts. He also says that the instruments are so successfully pacified that they operate the same as though the wires were free from induction from other circuits. Two carbon-rod shunts are used, *a* being connected in parallel with the relay winding and *b* from the one binding post of the relay to an auxiliary battery; the other terminal of this battery is connected to an insulated back stop of the relay. The non-inductive shunt *a* not only gives a path of less impedance than the relay coils, for the induced rapidly changing or alternating current, but also allows the kick or discharge of the relay coils to pass through it. When the relay armature falls back, the auxiliary battery sends current through the relay coils and the high resistance *a*, which are in parallel, then through the carbon-rod resistance *b*, thereby magnetizing the relay cores enough to overcome the influence due to the induced current that may pass through the relay coils, but not enough to overcome the retractile spring, hence the armature is not moved.

Where the tendency of the relay to act sluggishly in response to the home key is not too great, the auxiliary battery may be omitted, in which case one end of the resistance *b* is connected directly to the back contact stop of the relay. The proper resistances for shunts *a* and *b* should be experimentally determined. In some cases, satisfactory results have been secured with a resistance of 350 ohms for *a* and 500 ohms for *b* with an auxiliary battery of six cells giving about 7 volts. Previous to the use of this *static pick-up*, as it is sometimes called, certain circuits had to be completely metallic and free from ground connections; by its use a single wire with ground return could be used.

15. Eliminating Severe Disturbances to Telegraph Systems.—The methods so far considered are satisfactory only for small disturbing currents. When the amount of power transmitted, length of lines paralleling one another, or small separation of the two circuits is such as to make the disturbance severe, more definite neutralizing conditions must be secured. If voltages equal and opposite to those developed by

electro-magnetic and electrostatic induction are introduced into the telegraph line, the inductive disturbance can be eliminated.

Fig. 3 shows one way in which this idea may be worked out. Current transformers, connected as shown at *a*, introduce into the telegraph line a potential that opposes that induced in the line itself and is proportional to the current in the alternating-current line. A non-inductive resistance is connected at *b* to keep inductive resistances out of the path of the signaling current. Since, on an electric railway, the position of the car, and hence the load, is shifting, it would be necessary to divide the line into sections (say 2 miles in length) with a transformer for each section. The shorter the sections the more exact the neutralization. Electrostatic induction is neutralized by

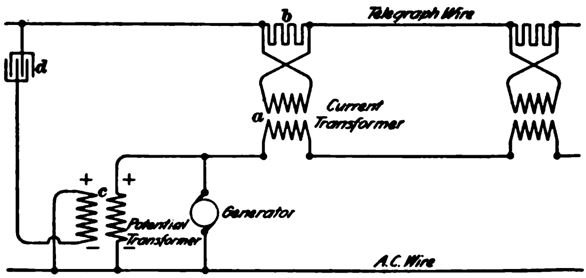


FIG. 3

using a condenser *d* in connection with potential transformer *c*. The proper charge can be obtained by varying the capacity of the condenser *d* or the voltage applied to it. The primaries of these transformers are connected directly in the disturbing wire.

16. Neutralizing Wire.—Instead of using current derived directly from the disturbing wire for the neutralizing purpose, the neutralizing currents may be secured from a special neutralizing wire run along close to the disturbed telegraph wires. As the neutralizing wire will be exposed to the same extent as the telegraph wire, the same voltage will be induced in each wire, and a one-to-one transformer, that is one having approximately the same number of turns in each winding, with one winding in each disturbed wire, may be used to produce in the

disturbed telegraph wire a voltage equal to and opposite to that induced directly by the power wire in the telegraph wires. By the use of a transformer having a number of secondary coils and one primary, one neutralizing wire centrally located may suffice for a number of telegraph wires.

This arrangement, while effective, is not always sufficient, as it is seriously interfered with by leakage from direct-current trolley lines, which energize these transformers. Variation in load in the alternating-current circuit and phase distortion add materially in preventing anything more satisfactory than an amelioration of the harmful inductive effects. The arrangements hitherto offered to eliminate inductive disturbances have been rather of a palliative than of a positive remedial nature. As the tendency is to increase the use and potentials of high-tension transmission circuits, to overcome the disturbances due to them may constitute the most serious problem confronting telegraph engineers.

17. Metallic Circuit as Remedy.—In spite of any of the arrangements that have been offered to reduce disturbing inductive effects, it may be cheaper or more satisfactory in some cases to use a complete metallic circuit for the telegraph. A metallic telegraph circuit will almost always be less sensitive to inductive disturbances than an earth-return circuit, but to obtain the full benefit of a metallic circuit it should be properly transposed, according to the following general rule:

Rule.—*Treat as one section the distance between two consecutive changes of any character in any of the disturbing circuits, and transpose each pair of wires constituting a metallic telegraph circuit at the middle of each such section.*

These changes, or discontinuities, in the disturbing circuits occur where an arc light is inserted in one of the circuits, or where a transformer is bridged across the alternating-current circuit, or where any of the circuits change abruptly in direction or distance from the telegraph circuits, or where additional alternating-current circuits begin to parallel or leave the telegraph pole line, or where any of the disturbing circuits are transposed. For minimum disturbance, the two wires of the

same size and material constituting a metallic telegraph circuit should be kept as close together as practicable, the power

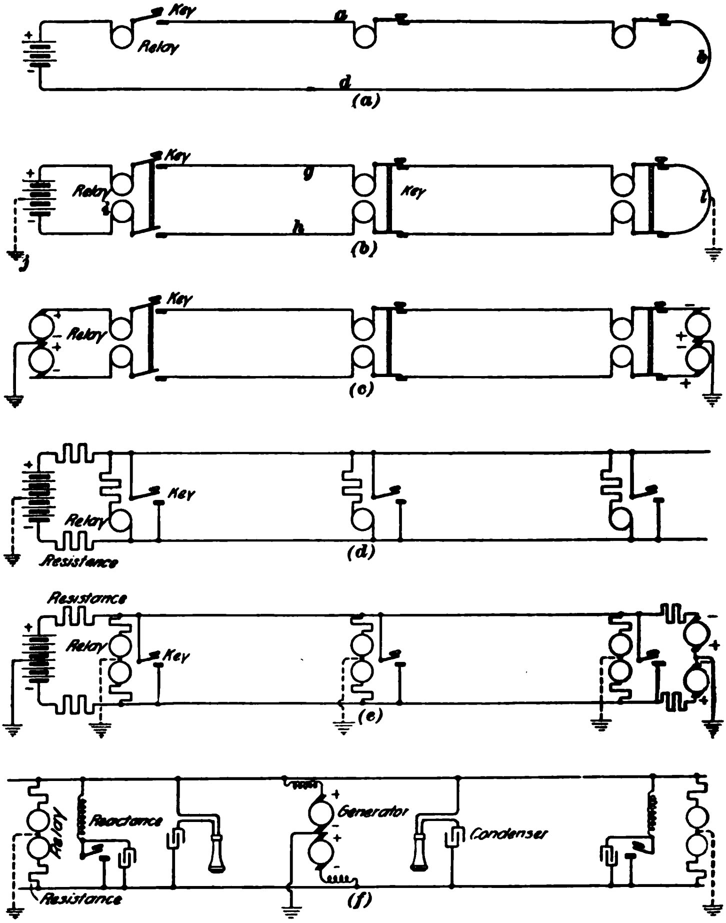


FIG. 4

or light wires as close together as practicable, and the two systems as far apart as possible.

18. Instruments Bridged or in Series.—Pieces of apparatus, such as telegraph relays or telephone bells, bridged between two properly transposed wires are usually free from

inductive currents. If the apparatus is connected in series in the line, in order to remain undisturbed, it must not be connected in one side of the line only, as shown in Fig. 4 (*a*), but must have two separate windings, one properly connected in each side of the line, as shown in (*b*). Then if induced currents flow for example from the points *g* and *h* through the two relay coils and battery to ground *j*, the relay will not be affected, but the signaling current, flowing from *h* through the lower coil of the relay, battery, and upper coil of relay to line *g*, will operate the relay as usual.

19. Fig. 4 shows several connections that may be used for a metallic circuit telegraph system. In (*a*) is shown an ordinary series telegraph system with a wire in place of the earth as a return circuit. If the conditions are such that electrostatic effects can be neglected, this arrangement, although the two sides are not balanced, will be satisfactory.

Views (*b*) and (*c*) show balanced, metallic-circuit, series, telegraph systems. In these cases, each relay must have two windings differentially connected and double-pole keys must be used. In (*b*), in which a battery is used, the ground at the center, or neutral, point of the battery and the ground at the end *l* may or may not be used. The purpose of a neutral ground in all cases is to keep the system, as a whole, at approximately earth potential. In (*c*), generators are shown at each end of the line with their neutral points grounded. Each generator may consist of two generators of equal voltage and connected in series, with their connecting wires grounded.

20. Views (*d*) and (*e*) show a metallic-circuit telegraph system with relays connected in multiple, or bridged between the two sides of the line. With this arrangement it is essential to have the relays wound to as high a resistance as practicable, and it may be advisable to place additional resistances in series with each relay as indicated. Resistances of sufficient value are inserted between the battery, or generator, and the line, so that closing any one of the keys will cause a sufficient fall in potential at all relay terminals to allow the relays to release their armatures. A battery is shown at one end of the line

only in (*d*), while in (*e*) energy is supplied from both ends. In (*d*) the neutral point of the battery and in (*e*) the neutral points of the relays may or may not be grounded, as indicated by the dotted lines. In (*e*) the neutral points of the battery and generator are shown grounded.

View (*f*) shows a combination of the metallic-circuit bridging telegraph with the bridging telephone. In place of the telephone there might be substituted some form of alternating-current telegraph system. This arrangement, being balanced for both the direct- and alternating-current systems will be free from inductive disturbances and similarly, if properly transposed, will not cause disturbance in neighboring circuits, a trouble frequently experienced with alternating-current telegraph systems.

TELEPHONE CIRCUIT DISTURBED BY TELEGRAPH LINE

21. The effect due to electromagnetic or electrostatic induction of one circuit on another may be reduced by using two wires for each circuit and placing the two wires of each circuit as near together as possible and the two circuits as far apart as possible. If the two wires of each circuit are also twisted together or transposed, the disturbing effect may be still further reduced.

If a line consists of a single wire, grounded at both ends like a telegraph line, and is equally distant from the two wires of another circuit with no earth connections, like a complete metallic telephone circuit, for instance, it will produce no disturbance in the telephone circuit. This would be the case where the telegraph line is directly below or above and equally distant from both telephone-line wires, and there would be no need or use of transposing the telephone wires. But if the telegraph-line wire is on the same cross-arm as the two telephone wires, or arranged in any manner so as to be nearer one telephone wire than the other, transposing the disturbed telephone wires often enough will eliminate the trouble if due to electromagnetic or electrostatic induction.

On long telephone lines, induction is very troublesome, and transposing the wires in this manner is universally adopted, the transpositions being made about every 1,300 feet.

In cables, electrostatic and electromagnetic induction may be eliminated by twisting the outgoing and return conductor of each pair spirally around each other throughout the length of the cable. It is not customary to use two wires in each circuit and to twist one around the other in telegraph cables, but it is invariably done and is absolutely necessary in telephone cables, because the telephone receivers are so extremely sensitive to variable currents.

22. Induction and Earth Currents in a Submarine Cable.—The working of an ocean cable at Cape Town, South Africa, was seriously interfered with by the electric railroad that ran more or less parallel to it for about 5 miles, the land cable being quite close to the car line, and the first mile of the shore end of the submarine cable being only at a mean distance of about $\frac{1}{2}$ mile from the car line. It was conclusively determined that the most serious trouble was due to the return currents from the trolley line seeking the sea and the sheath of the cable as a return path. However, it had also been observed that the automatic circuit-breakers at the railway power house sometimes broke their circuits, through which 350 amperes were flowing, half a dozen times within 15 minutes, and of course were closed again each time. Prof. A. Jamieson (the consulting engineer in the case) says that such sudden stoppage and starting of a current of 350 amperes at 500 volts undoubtedly causes direct electromagnetic induction in all neighboring parallel electrical circuits, whether they are in the air, as in the case of overhead line wires, or buried in the earth, or laid in the form of a submarine armored cable in the sea. These sudden electromagnetic disturbances are, however, distinguishable by the behavior of the cable instruments from the disturbance due to leakage or stray return currents from the railway circuit.

23. Remedy for Induction and Earth Currents in a Submarine Cable.—The whole trouble has been remedied by running a two-conductor cable some miles out to

sea to an island, where one conductor is grounded by soldering it to the cable sheathing. The two conducting cores are insulated from each other and symmetrically twisted about each other, the whole heavily armored, and the land cable also armored and enclosed in a heavy cast-iron pipe laid underground from the cable hut to the cable office, a distance of 430 yards. By twisting the two conducting cores about each other, an anti-induction cable is obtained, so that even the making and breaking of the whole trolley current at the railway power house produces no current in the cable conductors by electromagnetic induction. Furthermore, although the trolley current may still flow in the armor, the latter no longer forms part of the cable circuit near the shore, and so the trolley current does not flow in the cable circuit. Neither can the variable trolley current in the armor induce a disturbing current in the cable conductors, because they are twisted spirally about each other, and are hence, on the average, equally distant from the armor throughout the shore end of the cable. Thus the cable conductor is shielded from induction as well as from forming a path for the trolley current. The receiving instruments used with submarine cables are extremely sensitive, requiring an extremely small current to operate them, and for this reason they are much more easily disturbed and need more protection than instruments used on land lines.

24. To get rid of the disturbances due to trolley currents on the Western Union cable running from Broad Street, New York, to Canso, Nova Scotia, it was necessary, about 1892, to extend the ground wire from Broad Street to a point 1,500 feet from the Coney Island shore. The two wires in this case, the cable conductor and the grounded wire, were not in one core and twisted together, so that it was necessary to heavily insulate the ground wire until reaching the point where it was grounded independently of the cable sheath from which it was separated as far as convenient. If the two wires had been twisted spirally about each other and enclosed in the same armor, as in the African cable, which is much the surer

and better way, this separating of the grounded end from the cable armor would not have been necessary, and the trouble that the above treatment did not entirely eliminate would doubtless have been cured without a change in the receiving apparatus, which was also required.

FAULTS ON TELEGRAPH LINES

CAUSES OF FAULTS

25. Some of the causes of faults or interruptions to which an aerial line is subject are the following: The line wire may come into contact with other wires on the same poles by the position of the pole itself, by falling branches, trees, or rocks, by high loads at crossings, by whip lashes, by kite strings and tails, by careless workmen, and even by the wind itself when very high. Loose or broken arms, brackets, or pins, may allow the wire to come into contact with poles, walls, bridges, and trees. Trees, unless they are kept carefully trimmed, may grow up among the wires. Joints may become bad from the absence or failure of solder or from being otherwise improperly made. Malicious or thoughtless persons may twist the wires together or cut them. In addition, atmospheric disturbances, such as rain, fog, and dew, affect the resistance of the line, and the smoke of factories is very liable to cause variations. Subterranean and submarine wires are free from these vicissitudes. The resistance of their insulating covering is practically constant. The most common faults to which telegraph circuits are subject are defective insulation, causing escapes or a partial ground, a dead ground, crosses, breaks, and defective ground connections at one or both terminals.

BREAKS

26. When a telegraph-line wire breaks, one of three things may happen: (1) neither of the broken ends may touch the earth or become grounded; (2) one end only may become grounded; (3) both ends may become grounded. In the first case no current, and, therefore, no signals, can be sent over the line between the offices between which the break occurs. In the second case, no current or signals can be sent from the office toward the open end of the line, but, from the office on the grounded side of the break, the resistance may be much reduced and a large current may flow to earth through the grounded line, giving very strong signals if the key is manipulated. In the third case, an abnormally large current may flow through the two grounded wires from the stations on each side of the break. The offices on opposite sides of such a break cannot communicate with one another, but offices on the same side of the break may communicate with one another. Besides the above three cases, there may be a partial break and a swinging break. A **partial break** occurs when the resistance of the line is greatly increased. It may be caused by a bad joint due to rust or corrosion, by dirty or poor contacts in the instruments, bad connections at binding posts, or elsewhere, or by poor ground connections, or a defect in the main battery or by its not being in proper condition. A partial break weakens the current so much that the instruments in circuit work very weakly. A **swinging break** opens and closes the circuit at regular or irregular intervals of time, and may be caused by the effect of the wind on a loose joint in the line wire or from a loose connection in the office.

GROUNDS

27. A telegraph line may become unintentionally **dead grounded** or **partially grounded.** When dead grounded, all of the current, and when partially grounded, but part of the current, escapes to the ground. A dead ground will affect the circuit in the same manner as a break where both ends are

grounded. Offices on the same side of a partial ground can communicate with each other about as usual, but a key in any part of the circuit cannot fully control the current in that part of the circuit beyond the partial ground. Messages may be transmitted past the partially grounded place with more or less difficulty, depending on the magnitude of the current that escapes at the partial ground.

28. Reducing Leakage Due to Grounds.—Leakage due to a dead ground can only be overcome by locating the dead ground and removing it. Partial grounds due to poor insulation all along the line can only be reduced by improving the insulation of the whole line. It may be only at some one place that the insulation is bad, and a careful inspection from office to office toward the suspected bad place will generally enable it to be located and removed.

29. Leakage From Other Lines.—If the insulation between a telegraph line and a neighboring line is very poor, a part of the current from the neighboring line is likely to pass by leakage to the telegraph line and it may be large enough to affect the relay thereon. This is especially true where both lines are grounded. When, on account of defective insulation due to wet weather, there is leakage from one telegraph line to another supported on the same poles, there is said to be a *weather cross* between the two wires; another name for it is *cross-fire*. It causes more interference in the working of lines than the mere escape of current to the ground. The tendency is for the current to escape from a long or high-resistance line to a shorter or lower resistance line.

30. Overcoming a Weather Cross.—An escape to the ground, if not too great, may be remedied by a judicious increase in the battery power, but when the trouble is due to a weather cross, an attempt to improve the working of one line by using more battery on it produces a more harmful effect on all the other wires on the same poles.

A weather cross may be prevented by running a wire that is well grounded at the bottom of the pole up the pole and along each cross-arm in such a position, however, that the

line wires cannot possibly touch or swing against it. The leakage currents will then go to the earth instead of to the neighboring wire. Make a flat coil out of about 10 feet of the wire used for this purpose and place it under the butt of the pole. The branch wires attached to the vertical wire may be wrapped around the central portion of the cross-arms, or run along under the cross-arms. But this grounded wire should not be fastened to nor touch the steel pins on which insulators are sometimes supported. This would cause excessive leakage to the earth in wet weather, and, in case the wire was not well grounded, it would help the leakage from one wire to another.

This method of overcoming a weather cross will increase the leakage from all the line wires to the ground, but the battery may be increased as much as is necessary on any one wire without interfering very much with the working of the other lines. Weather cross is much greater near the ends of a line, and especially in cities near the terminal offices and where the insulation is usually poor. It is advantageous, therefore, where weather cross is troublesome, to apply ground wires to the poles for 15 or 20 miles from each terminal office.

CROSSES

31. Crosses may be caused by a permanent contact between two line wires, or they may be what are called swinging crosses. Where two or more telegraph lines are crossed they cannot all be worked at the same time. However, any one line can be worked as if there were no cross, by opening all the others.

A *swinging cross* is caused by one wire swinging against another, but remaining in contact only a short time. It is very annoying, for it is very difficult to locate by any tests, on account of its short duration, and usually the only way to locate it is by a careful inspection. When the line swings against a tree, pole, roof, or other partial or good grounded conductor, a *swinging ground*, which is also difficult to locate, is formed.

TESTS WITH RELAY AND KEY

INTRODUCTION

32. Simple, but complete, tests are here given for determining the nature and location of faults on telegraph wires, that require only the use of an ordinary relay, key, and usually also a sounder and battery. When an office set is mentioned, it means an ordinary relay and key. It will frequently be necessary to refer to Fig. 5, in which *1*, *2*, and *3* are simple line circuits, each consisting of one line wire, a relay, key, and switchboard or cut-out device at each office and 150-volt batteries at terminal stations *A* and *B*, which are, say, 250 miles apart; *C*, *D*, *E*, *F*, *G*, and *H* are way, or intermediate, offices.

Except where otherwise stated, it will be supposed the operator making the tests is located at the terminal office *A* and that *A* is the east and *B* the west end of the line. It will

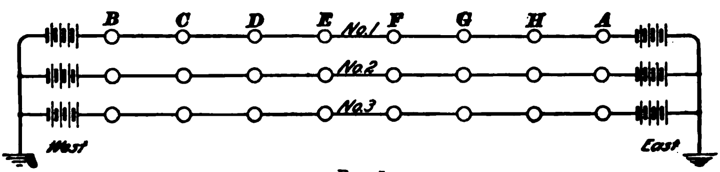


Fig. 5

be assumed that the *A* operator has made sure that there is nothing wrong with his own office instruments and circuits, although if the test indicates a fault in the office, the fact will be stated. In all cases of trouble, the operator should suspect that the fault is in his own office and should first look for it there. When a relay is inserted in any circuit and no current is indicated by the refusal of the relay to work, it will be taken for granted that the relay has been properly adjusted, either low or high, or both ways in turn, in order to be sure that there is no current, either small or large, through the relay. A current through the relay, whether large or small, may usually be detected by feeling with the fingers for a pull on the armature.

33. As soon as a line wire, say No. 1, gets into trouble, or is reported in trouble, and it is desired to test the wire and locate the fault, almost invariably the first thing to do, is to "feel of the wire" to ascertain the nature of the trouble. The ability to feel of a wire was long considered possible only to the oldest and most experienced wire chiefs, but technical education is dispelling this idea. The operator, who is about to make the test, will first cut in an office wire that is known to be all right. For testing purposes, this office set is always located on the table of the switchboard in the larger offices. After adjusting, it may be found that there is no current in the line, a very small current, or a very large current.

OPEN CIRCUITS

34. No current in the relay may be due: (1) to a broken line wire, (2) to an open key somewhere in the line or some similar act of carelessness, or (3) to there being a reverse electromotive force opposing that at the testing station and neutralizing its effect. To determine if the last is true, *A* will reverse or change the polarity of his battery or other source of electromotive force in the line. Should this close *A's* relay, either *B* has reversed his battery, or other source of electromotive force, or the wire is crossed with a line that is supplying an opposing electromotive force. The latter is the more probable and a test should be made for a cross, as explained in Art. **39.** But should *A*'s relay remain open when he reverses his battery, the static test should be used to determine how far away the opening is.

35. Static Test for an Open Line.—The charge an open line will take on account of its electrostatic capacity may be utilized to test for and approximately locate a break in a line wire. The test may be made at a terminal or intermediate office; it is commonly called the **static test for an open line.** To make this test connect the opposite terminals of a battery to the opposite sides of a double, or battery, plug. Holding the battery plug firmly between the thumb and forefinger,

rapidly connect first one and then the other pole of the battery to the line. Should the opening be in or very close to your own office, no appreciable result will follow, but should the opening be far away toward B, the armature of the relay will close for an instant each time the battery is reversed. This rapid closing and opening of the relay is termed a ***kick*** and, as a rule, the strength of the kick is proportional to the distance from the testing office to the opening.

36. The strength of the kick may be measured by gradually pulling up the spring of the relay and continuing to reverse the battery rapidly. After making this test a few times an operator will be able to tell approximately the distance to the opening. In this case suppose the static kick has been a moderate one, which will indicate that the opening is perhaps half way from A to B. To locate this opening, A will cut in an office set on another wire, say *No. 2*, on which he can obtain the various offices and will call E and F. Should E answer first, A will ask him to "gnd" (ground, or put his ground plug on) *No. 1* west and say when he does so. After he gets the plug in place, E replies "now." If this closes the circuit through A's relay that is cut in on *No. 1*, the opening is evidently west of E; in this case, A should call D. But if A's relay does not respond when the line is grounded on the west side at E, A should tell E to take it off and ground *No. 1* east. If this closes A's relay, line *No. 1* is open in the office at E and A should ask him to close it. But if A's relay still stands open, he must call F and proceed as before. That is, A asks F to ground *No. 1* west and say "now" when he has done so. If this closes the relay on line *No. 1*, then the opening is evidently west of F; if the relay does not respond, A must tell F to take off the ground and put it on the east side of line *No. 1*. If this closes A's relay, line *No. 1* was open in the office at F and A should request him to close it; but if A's relay still stands open, he must call G.

If line *No. 1* closes when it is grounded on the west side of the switch at F and opens when grounded on the east side of the switch at F, a loose or broken connection at the top of the

switch at *E* or *F* should be suspected and both *E* and *F* should be asked to examine the line connections at the top of their boards. Should they find no broken or loose connections there, the open circuit is caused by a broken wire between stations *E* and *F* and a lineman must be sent out to find and repair it.

37. Static Test With One Battery.—A very convenient arrangement to test for and approximately locate a break in a line wire, and one that requires only one battery, is shown

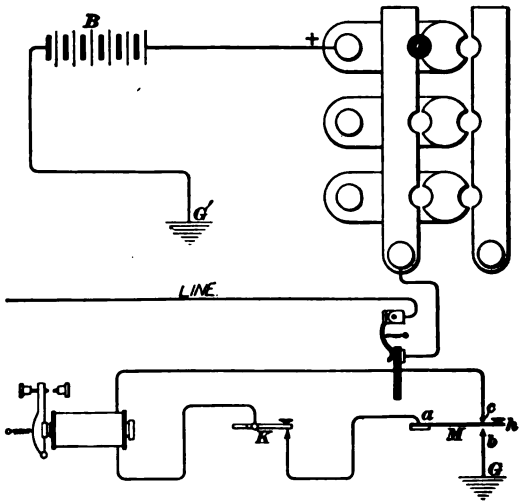


FIG. 6

in Fig. 6. Place a plug firmly in the hole *E* so as to connect the battery to the vertical strap of the line to be tested, and in the spring jack of the same line insert the wedge of an office set. In circuit with this office set is a special key *M*, called a **discharge key,** such as is used in making regular electrostatic capacity tests on cables, lines, and condensers. One wire from the ordinary telegraph key *K* is connected to the lever of the key *M* at *a*. The lower insulated contact *b* of this special key *M* is connected to the ground, and the upper insulated contact *c* is connected to one side of the wedge that is placed in the spring jack of the line to be tested. The lever *h* of the

key *M* should be made to touch both contacts *b* and *c* in rapid succession. When the lever *h* touches *c*, the line is connected through the office instruments to the positive pole of the main-line battery *B*; when the lever *h* is pressed down against *b*, the line is connected through the instruments to the ground *G*. Thus, the line may be rapidly and repeatedly charged to the potential of *B* and discharged to the ground potential.

38. Static Test at an Intermediate Office.—At an intermediate office, this same test can be made, provided the intermediate office is not too far from the main battery. Suppose that the east wire is open. Then, with the relay and key connected in line circuit as usual, and as shown in Fig. 7, the test is made by rapidly connecting and disconnecting the ground disk on the battery side of the circuit with a plug at the hole *a*. When there is no plug in the hole *a*, the line is charged to the potential of the main-line battery, the charge for the open east end having passed through the relay. When the plug is inserted in hole *a*, the discharge from the open end flows through the relay to the ground *G*. If the capacity of the open end is sufficient, and the voltage of the main battery not too low, the relay will respond each time the ground *G* is connected and disconnected. In any of these static tests, if the relay does not respond with a normal adjustment, it should be turned down until the kick appears, or until satisfied that there is no appreciable charge to or from the line, in which case the line is open near by.

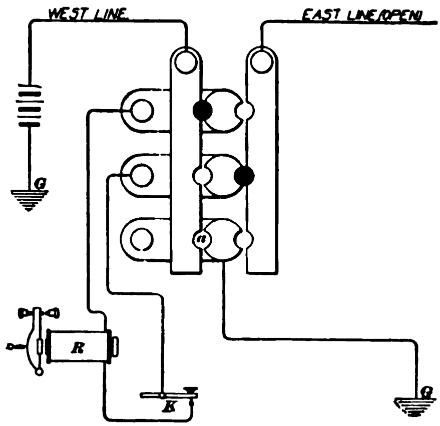


FIG. 7

CROSSES

39. Locating a Cross From a Terminal Office.—Suppose that line *No. 1*, Fig. 5, is reported in trouble and that *A* finds that reversing his battery closes the circuit. To determine whether this is a cross with line *No. 2* or *No. 3*, he should take a light hold of the armature of the relay by the thumb and forefinger and with the other hand slowly open and close first *No. 2* and then *No. 3*. If, when opening and closing *No. 3*, he feels a slight difference in the pull on the armature of the relay cut in on *No. 1*, then *No. 1* and *No. 3* are crossed. Calling *E* on *No. 2* as before (because he is about half way) *A* should ask him to open *Nos. 1* and *3* and say when. When *E* replies that they are open, *A* should cut in a third set on *No. 3* and put a positive battery on *No. 1* and a negative on *No. 3*. If, upon opening the key and dotting on *No. 1*, he finds the relay on *No. 3* acts in unison, the cross is between *A* and *E*.

A should now tell *E* to close *No. 1* (or *No. 3*, whichever is the more important wire) but to leave *No. 3* (or *No. 1* if of less importance) open. He may now cut the battery out of *No. 1* but must take the battery off *No. 3* to clear *No. 1*. He should then turn down the spring of the relay cut in on *No. 3* until it barely stands open and call up *F* on *No. 2* and ask him to open *No. 3*. When he replies that *No. 3* is open, *A* will lightly tap *No. 3* with his ground plug, when if the relay closes the cross is between *A* and *F*. He must therefore close *No. 3* at *F* and get *G* and test with him. If, when *G* opens *No. 3* *A* finds that he cannot close it at *A* even by putting battery on, the cross is between *F* and *G*.

40. By a little thought it will be readily seen how this same method of locating a cross may be employed at an intermediate office. Suppose that an operator is located at *E* and that *No. 1* and *No. 2* are crossed. To determine on which side of office *E* the cross is, ground *No. 1* east and call *B* on west side of *No. 1*. If *B* answers the cross is evidently east. Now ground *No. 1* west and call *G* on *No. 3*, and ask him to open *No. 1*. If the testing operator gets this opening on the relay

on line *No. 1*, the cross is between *G* and *A*. If he does not get the opening, the cross is between *E* and *G* and the operator must test in the same way with *F*.

41. The following method for locating a cross between two line wires between two way stations from a terminal office is also reliable: Have the distant end of the poorer, or less important, of the two crossed wires opened and insert a test set with the key open in the wire at the testing end. On this "thrown-out wire" the operator should ask some distant office to open this thrown-out wire, closing his own key after the distant office does so. If the cross is beyond the office called the wire will test open with either terminal of testing operator's battery connected to the line; but if the cross is on the home side of the office the testing operator will feel it when he closes his key. If the cross is beyond the office where it is now open, have the thrown-out wire closed there and try the next office. If the cross is closer than the office called, try the test with the next office on the home side. As the cross will be felt the instant the key on the test set in the thrown-out wire is closed, the other line wire with which it is crossed may be used continuously and no noticeable interruption caused.

42. Part of Line Rendered Useless By a Cross.—The only portion of one line that must be abandoned until the cross is repaired, is that portion of one line connecting the two offices between which the cross occurs. For instance, if lines *No. 1* and *No. 2*, Fig. 5, are crossed between *A* and *H*, either one of the two lines must be left open at both *A* and *H*, and the west end of it grounded at *H*; that is, at *H* this line must be grounded east in order to leave a relay set in it at station *H*. This allows one line to be used all the way through and the other from *H* to *B*.

GROUNDS OR LEAKS

43. Locating a Ground or a Bad Leak.—When feeling of a wire, as previously described, the operator may find a very light current on the line and may further find that it makes very little or no difference which pole of his battery is put to

the line; if the current shown by the relay is very slight, this denotes a ground far away toward *B*. Should a very heavy current be found on the line and should the operator upon pulling the spring away up still see no difference, no matter which pole of the battery is to line, then the wire is grounded near by. To further confirm this, he should remove the battery plug and turn down the spring on the relay fairly low, and then put in the ground plug; if no current appears, that is, if the relay still stands open, it is reasonably certain that the wire is grounded close by. He might, however, find, with the ground plug on, a fairly large current in the relay; this will denote a very heavy escape, provided the line is not crossed. The test to locate a ground or a heavy leak are identically the same.

44. Locating One Bad Leak.—Where the leaking current is so large at some one point that it is almost impossible

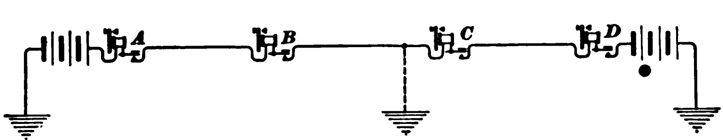


FIG. 8

to work past it, the fault may be located in the following manner: Suppose, in Fig. 8, that there is a bad leak or escape to ground between *B* and *C*, as indicated by the dotted line, and that office *A* desires to locate it. *A* will request each office in turn, commencing with *D*, to open his key. Evidently, opening the keys at *D* and *C* will not cut off the current leaking away between *B* and *C*, although it may weaken the current through *A* more or less. But if *B* opens his key, this leakage current will be entirely cut off and there will be little or no current through the *A* relay, assuming the line between *A* and *B* to be in good condition. Hence, the leak is between two consecutive offices, the opening of the key at one of which may somewhat weaken but does not entirely stop the current through *A*, while the opening of the key at the next office does entirely stop or very perceptibly weaken the current through *A*.

45. Another method of locating a bad escape on a line wire is to insert a voltmeter and a battery in series between a line and the ground at the testing office. Then have the way offices open their wires in turn, beginning at an office beyond the escape. A voltmeter needle will indicate the amount of escape until the first office between the escape and the testing office opens the wire, then the needle will show practically no deflection if the insulation of the line is in proper condition.

46. Slight Weather Cross.—To determine whether a slight weather cross exists, ask the distant office to open the circuit temporarily, while at the home office first positive and then negative potential of exactly the same voltage is connected through a suitable ammeter to the line. The reading of the ammeter should be practically the same for each polarity, if there is no wet weather or other cross between the line tested and another live circuit.

An observing wire chief is often able to detect this difference in the current strength due to positive and negative potential by means of his test relay alone, but sometimes a milliammeter is necessary. Occasionally, a voltmeter will show a discrepancy of this character that even a milliammeter will fail to detect.

A wire showing much of a cross with a live circuit should not be used for a duplex and much less for a quadruplex circuit. Even a larger leakage current, if not due to a cross with a live wire but merely to poor insulation, to ground, may not prevent the successful use of a line for either a duplex or quadruplex circuit.

47. Variable Leaks Between Stations.—Upon open pole lines the insulation is often so variable in wet weather that readings taken within a few minutes of each other will differ considerably and such readings are unreliable for use in formulas. In such cases the stations between which one or more bad leaks occur may usually be located in the following manner: Have the wire to be tested opened at a station beyond the leak and leave the terminal of the testing battery that gives the greater deflection connected through a

milliammeter or other suitable measuring instrument to the line. When the deflection becomes reasonably steady, watch the pointer closely while the wire is opened at the next station nearer the testing instrument. If the deflection suddenly drops, it is reasonably sure that the leak is between the two stations. If the pointer does not change much, have the wire opened at another nearer station while watching the pointer closely. A few tests will generally show between what two stations the leak occurs. Even when leaks occur between several stations, it is usually easy to tell between which stations they occur.

This method has the advantage of not depending on the value of any reading, and variations do not matter, provided they do not occur so suddenly that it is impossible to note the effect produced when the wire is opened at another station. Leaky sections can be accurately located by this method even when the readings are so variable that they do not remain constant long enough to compare them with a subsequent test to another station.

48. Cross Between Relay Coil and Iron Core.—If there is a cross between any part of the relay coil and the iron core, and if the armature strikes (which, of course, it should not do), or if any part of it or its support touches the iron core, or if the local circuit has any connection whatever with the iron cores, then a cross exists between the local and main-line circuits. This cross should be removed, for if the local circuit is grounded anywhere, there is an unintentional ground put on the main-line circuit, forming an escape or partial ground that may cause considerable trouble.

If the free end of a grounded wire is touched to the iron core and if the intensity of signals is then either greater or less, or if the working of the relay is entirely interrupted, then there is a cross between the relay coil and the core, provided there is a battery at both end stations. The effect produced will depend on the part of the relay coil that touches the iron core. If the test is being made at an end office where there is no battery, the signals sent from a distant station will not be affected,

provided the cross is located near the end of the relay winding farthermost from the line; but, if such is the case, and provided the cross is a good one, the operation of the home key, if on the ground side of the relay, will not operate the relay properly while the grounded wire is touching the iron core.

SWINGS

49. When temporary trouble occurs on a line frequently and, though lasting but a moment, causes confusion and errors, the wire is said to **swing.** Swinging wires are one of the most frequent troubles met with in wire testing. A broken insulator, a pin broken or pulled out of the cross-arm, thereby allowing the wire to swing freely with the wind, may cause great annoyance or necessitate abandoning part of that wire. In summer, hot weather causes expansion of the wires, thus allowing an abnormal slack between poles which a strong cross-wind converts into a swing; these are termed *swings to a cross.* A broken guy wire may drag on the ground and though mostly clear of the wires is often blown to and fro among them and as it strikes a wire part or all of the current is diverted to the ground; this is termed a *swing to a ground.* In wet weather the limb of a tree blowing against a wire will also cause a swing to a ground or heavy escape. All of these swings must be located so that a lineman may clear them by retying the wire, pulling out slack, repairing broken guy wires, or trimming the trees as the occasion requires.

50. Suppose line *No. 3*, Fig. 5, is reported as swinging and that it is desired to locate the same. First, to see whether or not line *No. 3* really does swing, *A* should have *B* open it, say for 5 minutes, while *A*, with a testing set (relay, key, and sounder), cut in on line *No. 3*, turns the retractile spring down until the relay just nicely stands open and watches closely, first with a negative battery to line for a couple of minutes and then with a positive battery for awhile. The reason for changing the battery polarity is almost self-evident, for if *No. 3* swings to a source of positive potential and there was at that

time a positive polarity to line at *A* the two sources of potential, if about equal, will neutralize each other and there will, consequently, be no current in the line whether contact is or is not made by the swinging wire. It is therefore necessary to use both polarities unless the swing is heard on the first trial. While watching, a quick closing of the relay, perhaps for an instant only, perhaps with a rattle, or perhaps for several seconds, is the evidence of a swing. To see if this swing is to a cross or to a ground, *A* will remove his battery from the line and substitute his ground. If taps are heard on the relay with the battery on, but none are heard, with the ground on, the swing is to a ground, but if any taps are heard with the wire to ground at *A* the swing is to a cross.

51. Locating Swing.—To locate a swing, begin by opening line *No. 3* about half way to *B*, say at *E*, Fig. 5. If no swing is heard, close at *E* and open at *D*. If the swing is now heard, the trouble is between *E* and *D*, but it is better to confirm this by testing again with line *No. 3* open at *E*. A swing to a ground is located in exactly the same way.

In the case of a swing to a cross, it is often necessary to throw out, by leaving open at each side of the trouble (in this case at *D* and *E*), the less important wire in order to clear a more important one. By leaving it open at *D* and *E*, this wire connecting *D* and *E* is dead and, so long as it is insulated, it does not matter if it touches one of the others or not, because there is no second circuit established. It is customary to work through a swing to a ground or heavy escape if it is not too frequent and there is no spare wire to patch it. Through an escape this may readily be done, by keeping the adjustment of the relay very high, that is, with the spring drawn up very tightly, so as to work on the margin or difference between what the current will be at *A* when the line is open at *B* with current escaping from the line only, and what the current will be at *A* when the line is closed at *B* with current escaping from the line and also passing through the distant station *B* to the regular ground plate.

52. Postal Telegraph-Cable Testing Arrangement for Locating Swings on Wires.—In Fig. 9 is shown an arrangement used by the Postal Telegraph-Cable Company for locating the two stations between which a swing on a wire occurs. The wedge *f* is inserted at a spring jack to which the wire in trouble has been connected at the switchboard. For a swing that grounds the wire in circuit with which a main-line battery or dynamo is connected, and causes the relay *r* to release

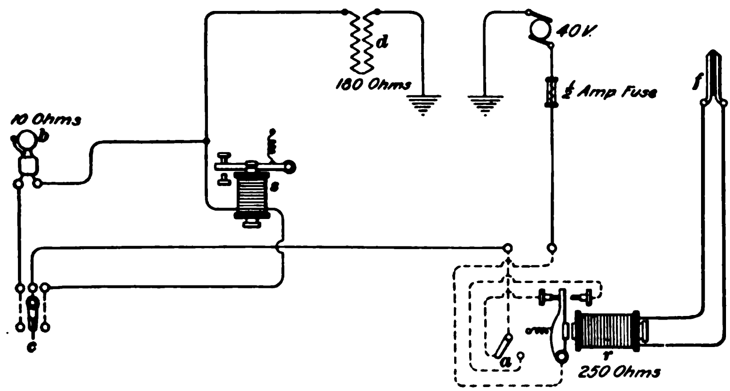


FIG. 9

its armature, the switch *a* is turned to the left, so that every time the relay releases its armature, the circuit of the sounder *s* or bell *b* will be closed, depending on whether the switch *c* is turned to the right or left, respectively. For a swing that momentarily introduces into the line a potential high enough to operate the relay alone, the switch *a* is turned to the right, so that the local circuit is closed each time the relay attracts its armature.

HEAVY WEATHER TESTING

53. During a steady rain, heavy fog, or after a fall of wet snow, the insulation resistance of telegraph wires becomes so very low that it is frequently necessary to abandon the lines because all the current leaks away to the ground. Under these conditions, testing for grounds, crosses, or swings becomes

very difficult and the utmost care must be exercised to guard against a false test.

In feeling for the distant battery, the testing operator is still supposed to be at A, the relay magnets must be drawn far back from the armature and the spring carefully adjusted until a position is secured where one pole of the battery closes the wire and the other leaves it open. Then the spring is drawn just a little tighter to be safe. This adjustment is considered correct if, with the positive pole of the battery connected to the line at A, the relay attracts its armature. If, however, with the negative pole connected to the line, the relay attracts its armature and an extremely small margin or difference between the pulls on the armature is found, the probability is in favor of the wire being entirely grounded, the difference in the pulls on the armature being caused by the well-known fact that the negative pole connected to the line usually causes a lower resistance ground and a greater escape than the positive. Of course if there is a difference in potential between the home positive and negative batteries, the positive being the larger, the wire might still be grounded and the positive pole give more current, but in any instances given here it is assumed that the two are equal, namely, 150 volts.

54. A way to decide, almost absolutely, whether the wire is simply heavy or is grounded is to push the magnets close up to the armature and let the spring of the relay down until the relay barely stands open. Now, if applying the ground closes the circuit through the relay, the wire is almost surely all right and it is simply a matter of adjustment to get the distant offices.

An exception to this must be borne in mind. When the testing is being done in a large place where many electric roads are in operation, sometimes a large difference of potential exists between the ends of a grounded conductor, one end of which is grounded in the city and the other several miles out. Where the margin runs down low and the operator is in doubt as to the condition of the wire, whether open, grounded, or all right, he should call up some one about half way, say F, on another

wire and have him open the wire in doubt. This may not open the relay at *A* on ordinary adjustment, very probably not, but *A* should draw back the magnets and pull up the spring until the relay just stands open and then have *F* ground the line east (on the *A* side of the opening). If the relay now closes there is a heavy escape between *A* and *F*, but the wire is not open. He should take the ground off at *F* and close it there, and then call some one west of *F* and proceed as with *F*.

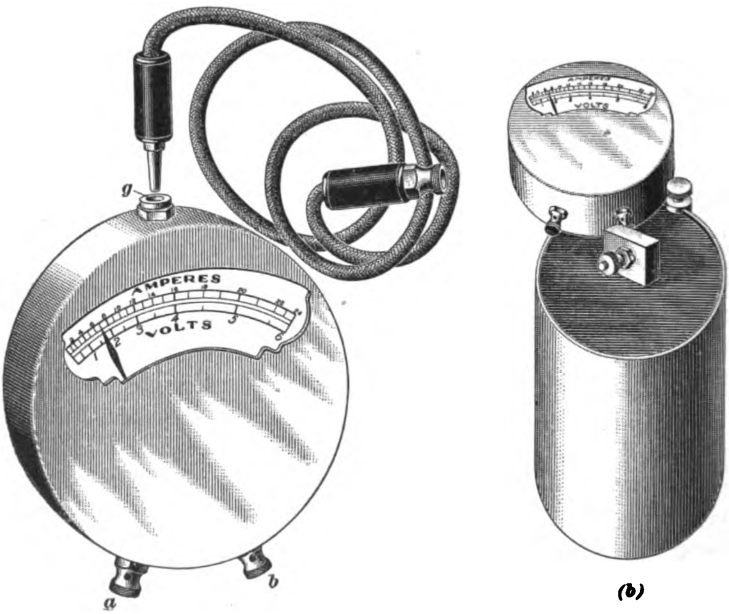
55. The logic of this may be explained as follows: The operator, to begin with, is in doubt whether the wire is grounded, escaped, or open and escaped. To settle one point the wire is opened at *F*; if the home relay stands open and if the current is escaping to ground the home relay must be adjusted above the escape until the relay stands open. When this has been done, the wire is open at *F* and the home relay is open. Now if the wire is intact no matter how badly escaped (except not absolutely grounded) then the home relay should close when *F* closes the wire. If the wire is open beyond *F*, the home relay will not close when *F* closes his key. Therefore, the line east is first grounded at *F*, when if the home relay closes the line is unbroken though badly escaped, as previously explained. As weather so heavy, caused by fog, rain, or wet snow, that it is absolutely impossible to adjust for or determine by the foregoing tests if a wire is all right to a point 100 miles distant, especially on way wires containing many relays, is frequently experienced, the wire will be found all right as soon as the weather conditions moderate.

SMALL VOLTAMMETERS

56. There are now upon the market a number of small ammeters and voltmeters suitable for testing the voltage and current output of single cells of batteries, or groups of batteries whose voltage does not exceed about 15 volts and the current does not exceed about 30 amperes. Such instruments are very convenient, especially for locating exhausted or defective cells in a battery. Both the voltmeter and ammeter are extensively

used for testing dry cells. Such an ammeter should never be connected directly across a storage cell to determine its current output and only across dry cells for as brief a period as may be necessary to note its reading.

57. A neat voltammeter made by The Connecticut Telephone and Electric Company is shown in Fig. 10 (*a*). The common terminal of both the voltmeter and the ammeter coils is connected to the post *g*, which is not insulated from the



(*a*) (*b*)

Fig. 10

case. Post *b*, which forms one terminal of the voltmeter coil, and post *a*, which forms one terminal of the ammeter coil, however, are both insulated from the case. Thus, by connecting a circuit from post *b* to post *g* or the case, its voltage is indicated by the needle on the lower scale, which is graduated from 0 to 6 volts. By connecting the circuit from post *a* to post *g* or to the case, the current flowing is indicated by reading the position of the needle on the upper scale, which is

graduated from 0 to 24 amperes. A flexible cord is provided with a terminal suitable for contact with post *g* and for extending the instrument circuit.

Dry cells may be conveniently tested without any connecting wires, as shown in (*b*), where post *b* is held against the carbon and the case against the zinc terminal of the dry cell. Voltmeters are made reading 0 to 3, 0 to 8, and 0 to 15 volts. An ammeter, reading 0 to 30 amperes, is made while voltammeters reading 0 to 24 amperes, 0 to 6 volts, also 0 to 30 amperes, 0 to 15 volts may be obtained. Standard-size dry cells should give a current, when momentarily short-circuited by such an ammeter, of at least 6 amperes; readings below that indicate that the cell is exhausted. New dry cells of standard size and good construction should give from 20 to 30 amperes, and 1.25 to 1.3 volts.

58. Determining Condition of Cells.—To determine merely if a cell or battery having an appreciable internal resistance, such as a gravity cell, is above a minimum standard condition, the following method is often used. If an ammeter, or other current-indicating instrument, which has no appreciable resistance, is connected directly in series with a battery, the current is limited practically by the internal resistance of the battery.

Determine, once for all, the minimum deflection that a cell in good working condition will give. Then, if the deflection falls below this with another cell or a whole battery, something is wrong with the cell or with one or more of the cells in the battery. No more current will be obtained from a whole set of cells connected in series than from one cell where the external resistance is negligible, because the total resistance of the circuit varies directly as the number of cells connected in series, and, hence, the total resistance varies directly as the total electromotive force.

When the deflection from a whole battery falls below the standard, a careful inspection may show one or more defective cells. If not, a defective cell may be located by testing each cell separately. If there is no especially bad cell in the set, the condition of the battery as a whole is poor.

This method cannot, of course, be used with batteries or cells that have little or no internal resistance. A storage battery, if tested in this way, would probably damage not only itself but also the instrument, on account of the large current that would flow, as the total resistance of the circuit is so small.

TELEGRAPH REPEATERS

(PART 1)

TELEGRAPH REPEATER CIRCUITS AND INSTRUMENTS

USEFULNESS OF REPEATERS

1. Necessity for Repeaters.—The **working efficiency** of a line depends on the relation of insulation resistance to conductor resistance. As the length of a line increases, therefore, the efficiency decreases until it becomes so small that satisfactory signals cannot be transmitted no matter how much the electromotive force of the source of energy may be increased. Even if the insulation could be made sufficiently perfect, as the length of the line increased the resistance would become so great that so high an electromotive force would be required to force the current through the circuit that it would not be safe, practical, or economical.

Furthermore, if the resistance of the line could be kept small and the insulation sufficiently high, and an electromotive force of sufficient strength could be used, the electrostatic capacity of a long line would be so high that it would seriously diminish the speed of signaling. For, the time required for the current to become strong enough to affect the distant relay increases as the electrostatic capacity C increases and also as the resistance R increases, hence the time increases as the product CR increases. On account of the retarding influence of the electrostatic capacity and resistance of the line and the

inductance of the relay coils, all of which tend to delay the rise and fall of the current, the duration of contact at the distant relay is less than that at the sending key, thus causing a shortening of the signals and, hence, a reduction in the number of good signals that can be transmitted in 1 minute. Moreover, an electromotive force above 300 volts requires very good insulation of the line wire and also tends to develop a ground or leak at every weak point. Poorly insulated lines that may work fairly well with a low electromotive force may act as if permanently grounded at some intermediate station if too high an electromotive force is employed. Therefore, *repeaters* are used on long transmission circuits to break up the line into sections of shorter lengths.

2. A telegraph repeater is an arrangement of instruments and apparatus whereby signals coming over one line are repeated or sent forwards on another line by a separate battery. A common relay is really a repeater, for it causes the sounder in the local circuit to repeat the signals that pass through the relay coils. Thus, if the relay is placed midway between two end offices, and if the line on one side is connected to the relay coils and the line on the other side to the local contact points of the relay, it becomes a one-way repeater; that is, it will repeat in one direction. The simplest form of a repeater would consist of two relays, one for repeating in one direction and the other for repeating in the other direction.

By the use of repeaters it is possible to work to very great distances. A line from London to Teheran, a distance of 3,800 miles, is worked directly by the aid of five automatic repeaters. In this country, on April 25, 1899, the Associated Press combined its circuits by the aid of repeaters, and formed a line 6,000 miles in length. The matter transmitted from New York for several hours was received in all the leading cities, requiring the services of 41 operators in all.

3. Firm or Heavy Sending Required.—On a very long line, very deliberate and firm, and, therefore, slower sending is required in order to get good signals on account of the retardation due to its large electrostatic capacity. In

such a case, the whole line, neglecting the leakage to earth at the insulators, has to be charged and discharged through the end offices. Now, if this long line is divided into sections, as when repeaters are used, each section will charge and discharge independently of the others; and as the sections are shorter than the whole line, they will all be charged and discharged quicker than if connected in one continuous line.

On a very long circuit with several repeaters, there is a shortening of the signals at the far end due to the fact that, as each circuit is closed, a short delay occurs in the successive transmission of a signal from one circuit to the next, because each armature in turn has to move over a short distance from the rear to the front stop before the circuit is complete. This shortens the dots and dashes in proportion to the number of contacts to be closed, and thus the dots are sometimes wholly lost. Therefore, in operating a circuit containing one or more repeaters, the dots and the dashes should be made firm and longer, or as operators term it, the "sending should be heavy." The more repeaters there are in a circuit, the heavier should be the sending. As a matter of fact, the loss in speed due to this latter cause is not so great as is the gain in speed due to the quicker charging and discharging of the shorter sections into which the long line has been divided. Thus, a long line can actually be worked faster and much more satisfactorily with repeaters than without, especially in wet weather, when the working efficiency decreases.

4. Distance Between Repeaters.—Moreover, by means of repeaters it is possible to work long lines with wires of a reasonable size, fair insulation, and electromotive forces not unreasonably high, that could not be worked as one continuous line. In America, with large and comparatively low resistance wires, it is not customary to operate, directly, a circuit over 600 miles in length. On well-insulated lines of good conductivity, and especially through dry regions, circuits are sometimes worked much longer distances without repeaters.

The line from San Francisco to New Orleans, a distance of 2,484 miles, is worked with only one repeating station,

which is at El Paso. This repeating station is even cut out occasionally and the line worked direct. The long stretch of country through Arizona, New Mexico, and Western Texas is unusually well adapted to long-distance telegraphy, the atmosphere being dry and rare. The atmospheric conditions along the California coast and in the swamps of Louisiana and Eastern Texas, through which the remaining portion of the line runs, are not favorable for long-distance telegraphy, but this has been overcome by using copper line wire and by taking good care of the insulators.

5. A line from Toronto to Vancouver, 3,228 miles, works fine in good weather with repeaters at Montreal, Fort William, Winnipeg, and Regina; from Montreal to Vancouver, 2,898 miles, consisting of 300-pound-per-mile copper wire, it works well even when quadruplexed. A line between New York and San Francisco is worked duplex with repeaters at Albuquerque, Kansas City, Chicago, and Meadville, Pennsylvania. From San Francisco to Albuquerque, the longest distance between repeaters, is 1,199 miles. When parallel wires are few and far apart fewer repeaters may be required. By the use of the direct-point repeater, the line from New York to San Francisco is worked as a polar duplex with one repeater.

BUTTON REPEATERS

6. Button repeaters require that a button, or switch be turned manually by an attendant, in order to change from repeating in one direction to repeating in the opposite direction. They are occasionally called **manual repeaters.** With such repeaters an operator must listen to what is passing and be ready at any moment to turn over the button, or switch, in order to reverse the direction in which messages may be sent and so allow the operator at the receiving end to send, and vice versa. Because it requires the constant attendance of an operator, a button repeater is generally employed only for temporary purposes.

7. Modified Wood Button Repeater.—About the best arrangement of the **Wood button repeater** is shown in Fig. 1. No provision is made in this arrangement for connecting the circuits straight across. This is not necessary in a repeater, because such connections can be made directly at the switchboard, including an ordinary relay in the circuit if desirable. When the switch M is turned to the left, the switch blade connects contacts c and d and the eastern circuit will repeat into the western. In this position the east line cannot be opened at the repeater station by any action of the sounder S_1.

When the switch M is turned to the right, the switch blade k connects contacts a and b and the western circuit will repeat into the eastern. In this position it is impossible for the

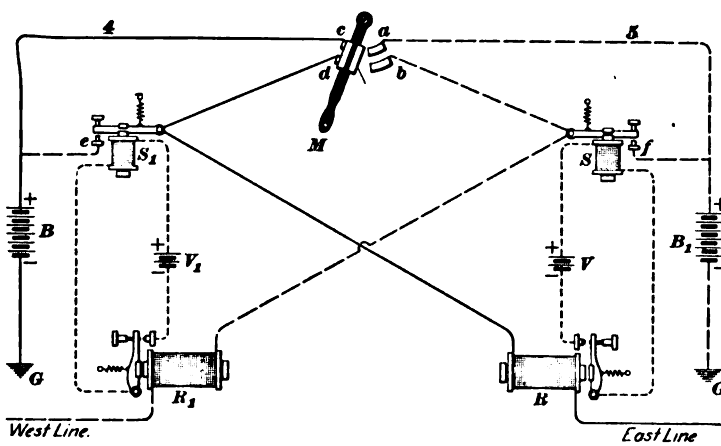


Fig. 1

operator at the western office to open the western circuit at the repeater station. When the switch M is in the center position, the blade connects contacts c and d and contacts a and b and two independent circuits are formed; namely, $G-B-4-c-d-R-$east line to eastern office and back through the ground to G, and $G_1-B_1-5-a-b-R_1-$west line to western office and back through the ground to G_1.

8. Operation of Wood Button Repeater.—If the switch M is placed so as to connect contacts b and a, the western

circuit will repeat into the eastern. If the western key is closed, a current proceeds from the plus pole of battery B_1, goes through the relay R_1, then to the western station, where the line is grounded, back through the earth to G_1, and to the minus pole of battery B_1. By this current, relay R_1 is caused to close its local circuit, which causes sounder S_1 to close the circuit of battery B. This circuit may be traced as follows: From the plus pole of battery B through contact e, relay R and east line to the eastern station and back through the ground to the negative pole of the battery B. The sounder S_1 repeats the message and the relay R operates the sounder S. No circuit is affected, however, by the armature of the sounder S, as its contacts are short-circuited by the switch M, which now connects contacts a and b together. It therefore acts merely as a reading sounder.

If the switch M is placed so as to connect contacts c and d, the eastern circuit will repeat into the western, and the circuits may be traced as before, beginning, however, with battery B and eastern line. In this arrangement, if the two sounders do not work in unison, the switch M must be instantly turned by the operator in attendance, so that the person receiving may be able to break and become the sender.

AUTOMATIC REPEATERS

PURPOSE OF AUTOMATIC REPEATERS

9. An **automatic repeater** is one that will automatically repeat in either direction without the necessity of turning a switch. An operator, however, is always needed to adjust the armatures of the relays and sounders, and to care for the batteries, but, of course, his time may be largely devoted to other duties.

MILLIKEN REPEATER

10. The **Milliken repeater,** although one of the earliest automatic repeaters used in telegraphy, is still regarded in the United States as a standard repeater; it is shown in Fig. 2.

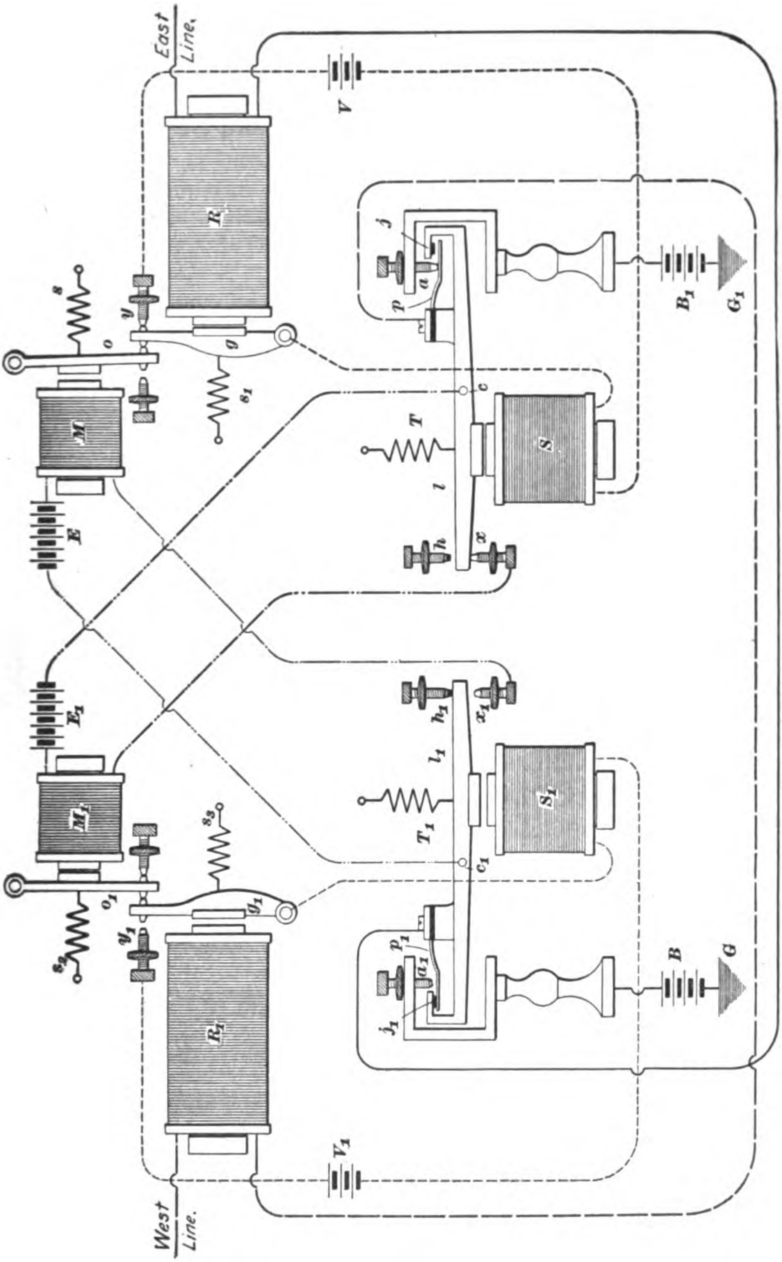


Fig. 2

The Milliken repeater is considered one of the best repeaters made, and its operation is entirely satisfactory. It requires, however, more local batteries than almost any other repeater, is not so easy to keep properly adjusted, and the extra local batteries must be kept in exceptionally good condition. The main-line relays R and R_1 are mounted on metal standards that hold them rigidly in place with respect to the extra magnets M and M_1. The levers of the relays and extra magnets are pivoted as shown, and the springs s and s_2 are so much stronger than springs s_1 and s_3 that the levers g and g_1 are pressed against the contacts y and y_1, when there is no current in either the relays R and R_1 or the magnets M and M_1.

The instruments T and T_1 are called ***transmitters***. When current flows through the electromagnet S, the armature lever l is attracted, causing the insulated spring, or ***tongue*** p, to come into contact with the stop a slightly before the other end of the lever l touches its contact x. When the current stops flowing through the coil of the transmitter, the lever is released, as shown at T_1, causing the contact at x_1 to be broken slightly before the contact is broken at a_1. The bent-over ends of the levers of the transmitters may or may not be tipped with insulating pieces j and j_1. Current is furnished by the main-line batteries B and B_1, local batteries V and V_1, and the so-called extra local batteries E and E_1. Magnets M and M_1 have each a resistance of 75 ohms.

11. Normally, all circuits are closed. The western main-line circuit may be traced from the western office through $R_1-p-a-B_1-G_1$, and the ground back to the western office. The eastern main-line circuit may be traced from the eastern office through $R-p_1-a_1-B-G$ and through the ground back to the eastern office. The local circuit of R_1 includes $V_1-y_1-g_1-S_1$, and the local circuit of R includes $V-y-g-S$. The extra local circuits, including the magnets M and M_1, are, respectively, $M-x_1-l_1-c_1-E$ and $M_1-x-l-c-E_1$.

12. Operation of Milliken Repeater.—Let it be supposed that all circuits are in their normal condition, that is, closed. If now, the western key is opened, the relay R_1 will

lose its magnetism, but the magnet M_1 retains its magnetism; hence, the armature g_1 is released by the relay magnet and is not held by the spring s_2; therefore, it breaks the local circuit containing the magnet S_1 between g_1 and y_1, causing the lever l_1, of the transmitter T_1, to first break at x_1, the extra local circuit containing M, and then to break the eastern main-line circuit between p_1 and a_1. Thus M is first demagnetized and the spring s presses the lever o against the lever g, so that when a moment later the relay R is also demagnetized by the opening of the circuit between a_1 and p_1, the lever g is still held against y, since the spring s is adjusted to overcome the pull of the spring s_1. Thus, the opening of the circuit containing the electromagnet S of the transmitter T is prevented. The opening of this circuit, when the western circuit is repeating into the eastern circuit, would be fatal to the successful operation of the repeater. Therefore, when the western key is opened, the eastern circuit is opened without opening the western circuit at the repeating station. In Fig. 2, the instruments are shown in their proper position when the western key is open.

13. When the western key is again closed, the circuits are closed between contacts g_1 and y_1, p_1 and a_1, and l_1 and x_1, in the order named. Thus a signal is sent into the eastern line by the closing of the eastern circuit between contacts p_1 and a_1 and, therefore, the western circuit repeats into the eastern. To repeat from the eastern into the western circuit, the foregoing actions are reversed.

The attendant, if necessary, can read the signals from the sound made by the transmitter lever l or l_1. If it is desirable to know just how the signals are being transmitted through the main-line circuits, a relay controlling a local sounder may be cut into either main-line circuit by inserting a double wedge, to the two sides of which the relay is connected, into either line jack at the switchboard.

The chief function of an automatic repeater is to automatically prevent the opening or breaking of the sending circuit at the repeater station. For instance, the transmitter that

controls the western circuit must not open the western circuit at the repeating station when the western circuit is repeating into the eastern circuit. The *opposite transmitter*, a term frequently used, may be defined as being the one controlled by the relay in the circuit that is being repeated into. For instance, when the western circuit is repeating into the eastern circuit, the transmitter *T*, Fig. 2, is the opposite transmitter, because it is controlled by the relay *R* in the opposite circuit, and this transmitter *T* must remain closed while the western is repeating into the eastern circuit.

14. Repeater Relay and Extra Magnet.—In Fig. 3 is shown the repeater relay and extra magnet commonly listed

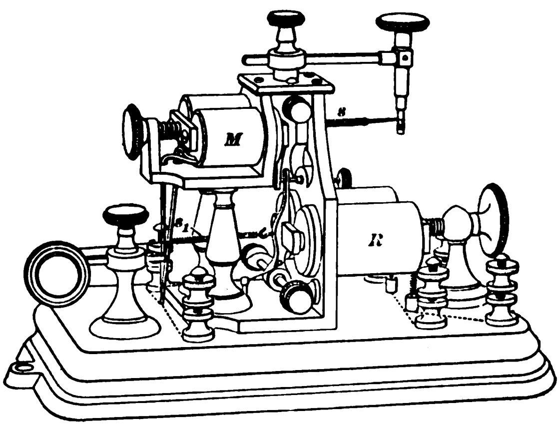


Fig. 3

and sold as the **Milliken-Hicks repeater.** The relay *R* is adjusted in exactly the same manner as an ordinary relay and the extra magnet *M* will seldom need readjustment if the extra local batteries are kept in good condition. The spring *s* must be slightly stronger than the spring s_1 and the armature of the magnet *M* must have no more movement than is necessary to allow the circuit to be opened. The extra local battery should be of sufficient strength and the cores of the extra magnet near enough to its armature and have a correspondingly strong

spring to insure an effective holding of the main-line-relay armature under any possible high main-line-relay adjustment.

15. Transmitter.—In Fig. 4 is shown one form of **transmitter.** The dotted lines show the connections between the binding posts in view and the stop-screw *a* and the tongue *p*. The tongue *p* is fastened to a piece of insulating material *i* that is in turn secured to the lever *l*. When used as part of a Milliken repeater, this transmitter has the lower end of the screw *h* tipped with insulating material. Some Milliken transmitters have two simple switches mounted on the base. When closed one connects (see Fig. 2) contacts *x* and *c* and the other connects the tongue *p* with a wire running to the positive pole

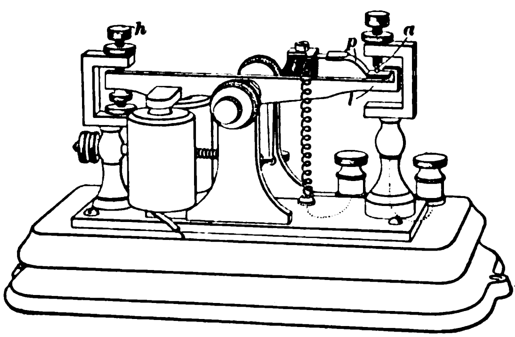


FIG. 4

of the battery B_1. When all four of these switches (two on each transmitter) are closed, the two extra magnets, including their local batteries, are on closed circuit and so hold their armatures o and o_1 permanently away from the relay armatures g and g_1, thus allowing the relays R and R_1 to operate as simple relays. Furthermore, the east and west lines are permanently closed by being shunted around the contact points of the transmitters to their respective main-line batteries and to the ground, and so prevent the movement of the transmitter levers from opening either the east or west line. Thus, each side of the repeater may be used as an independent circuit.

16. Adjustment of Transmitters.—In order to secure good connections at the contact points, the lever of the

transmitter, or *sounder*, as it is sometimes called, should have only movement enough to break the circuit, and the spring should be adjusted to have a very moderate tension, only a little more than enough to raise the lever when released by the magnet. The lever should have a play of about $\frac{1}{32}$ inch.

It often happens that the signals will pass through the repeater all right and yet be positively unreadable at the distant office, causing considerable misunderstanding between the operators at one end and at the repeater station. This is due to an improper adjustment of the transmitter contact points, due to the fact that the tongue p does not break contact, as it should, at the instant when the other end of the lever is exactly midway in its travel between the lower and upper stops. This incorrect adjustment causes the tongue to cling too long to one point and not long enough to the other. The signals will be too light, that is, too short, if the duration of contact between the tongue p and lever l, as the tongue end of the lever moves up, is too long, due to contact a being too high. The signals will be too sluggish, heavy, or long if the duration of contact between the tongue p and the contact a, as the tongue end of the lever moves down, is too long, due to the contact a being too low. Therefore, contact a should be adjusted to break just as the lever passes through the horizontal position and is midway in its travel, causing the duration of contact between the tongue p and the contact a and between the tongue p and the lever l to be equal. These remarks will apply to the adjustment of all forms of transmitters wherever used, unless something to the contrary is mentioned.

17. Milliken Repeater Operated by Dynamos.—In Fig. 5 is shown the actual connections of the Milliken repeater when the main and local circuits are all supplied with current from dynamos. In this case, one machine D_1 supplies the four local circuits and another D the two main-line circuits. The lamps L are of suitable resistance to allow the necessary current to flow in each circuit. The two main-line circuits from the repeater go to wedges $b\ i$ and $b_1\ i_1$ at the loop switch, then by *flying loops* to wedges $d\ f$ and $d_1\ f_1$ at the main switch,

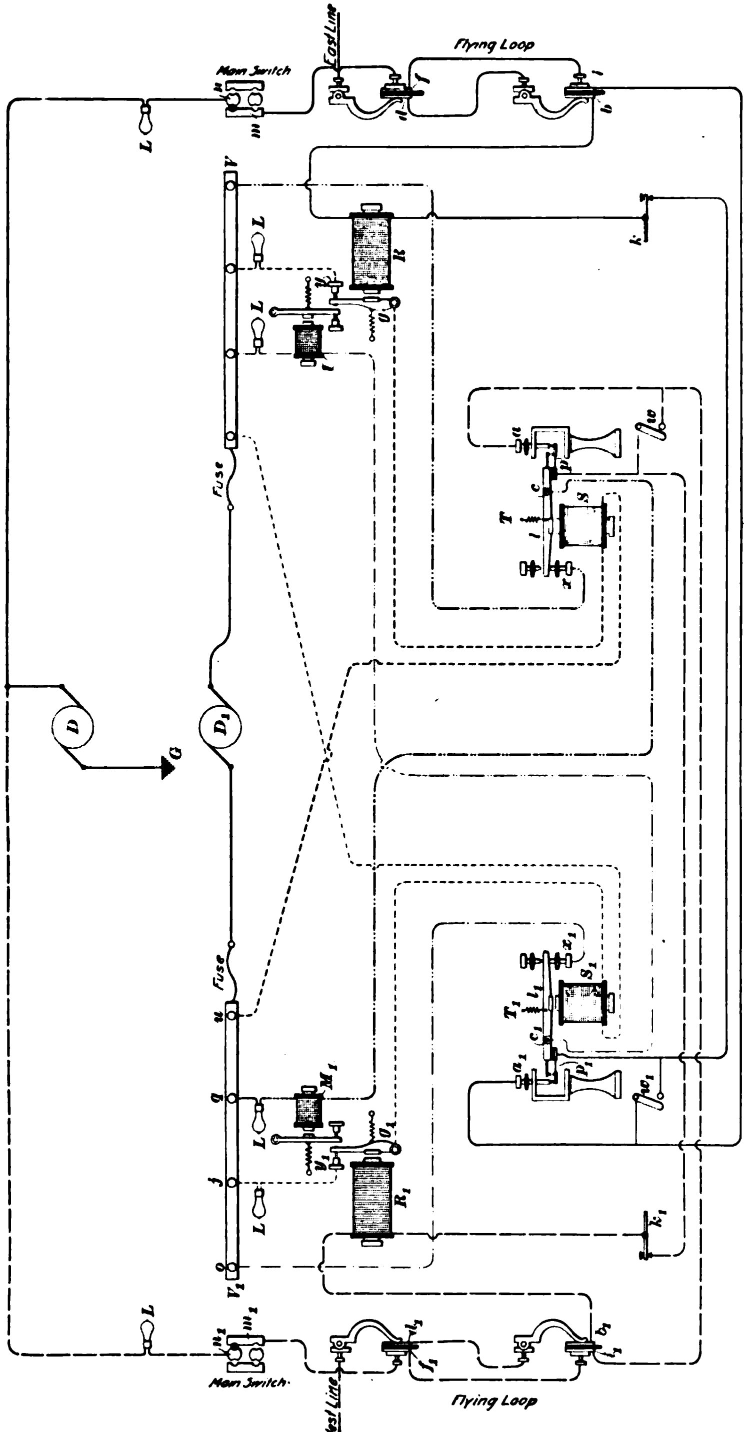

Main Switch
East Line
Flying Loop
Fuse
D
D1
G
Fuse
Main Switch
West Line
Flying Loop

FIG. 5

One side of each circuit then goes to a line, the other side through vertical straps m and m_1, pin plugs, disks n and n_1, lamps L and dynamo D to ground G. Keys k and k_1 and switches w and w_1 enable the attending operator to communicate with either of the two distant operators; the switches w and w_1 are closed only for this purpose.

The six circuits may be traced as follows: West line to $d_1-b_1-R_1-k_1-p-a-i_1-f_1-m_1-n_1-L-D-G$ back through the ground to the western office and line. East line to $d-b-R-k-p_1-a_1-i-f-m-n-L-D-G$ back through the ground to the eastern office and line. The extra local circuits are $D_1-V_1-o-x_1-l_1-c_1-M-L-V-D_1$ and $D_1-V_1-q-L-M_1-c-l-x-V-D_1$. The local circuits are $D_1-V_1-j-L-y_1-g_1-S_1-V-D_1$ and $D_1-V_1-u-S-g-y-L-V-D_1$.

The operation of this repeater, when supplied with current from dynamos, as shown in Fig. 5, is exactly the same as has been explained in connection with Fig. 2, where primary batteries were used. Consequently, the operation of this repeater should be readily understood without further explanation. All circuits are shown in their normal, or closed, position, and a newer type of transmitter is represented.

SIDE-LINE AND MULTIPLE REPEATERS

18. Most repeaters can be readily adapted to repeat from a main line at an intermediate station into a branch or side line. Furthermore, by continuing one main line through a number of repeater sets, the one main line will repeat into all the branch lines, or one transmitter may be made to have as many extra tongues and contact points as there are lines into which it is desirable to repeat. Automatic repeater sets arranged to do this are sometimes known as **three-cornered repeaters.** Automatic multiple repeaters have also been devised that, in one case, will repeat into eight, and, in another, into an almost unlimited number of circuits. However, the regular repeaters, which the telegraph companies have on hand, can be arranged to do this, so that no special multiple repeaters are in general use.

The Milliken repeater can readily be used for this purpose. Suppose, for instance, that it is desired to send from the through line between New York and Buffalo the same message to Syracuse by means of a Milliken repeater at Elmira. Suppose, further, that the eastern line in Fig. 2 is the one coming from New York. The battery B in this line may or may not be removed, but the line, instead of being grounded at G, would extend to Buffalo, where it would be grounded after passing through a relay and battery. The side line circuit would run from the ground G_1 through $B_1 - a - p - R_1$ at Elmira through the west line, in Fig. 2, to Syracuse. Thus the message passing over the main line from New York to Buffalo would be repeated into the side line running from Elmira to Syracuse. Furthermore, any one of the three operators located at New York, Buffalo, or Syracuse could send while the other two received.

TOYE REPEATER

19. The **Toye repeater,** which at one time was quite extensively used in the United States and Canada, is very simple, as is shown by Fig. 6. The only apparatus necessary in connection with this repeater that has not already been considered are two adjustable resistance boxes Y and Y_1. These are adjusted, as indicated, by means of brass pegs that may be inserted in holes between brass disks in order to cut out one or more of the resistance coils. The resistance in one box Y must be kept about equal to the resistance of the eastern circuit from the point a to the ground at the eastern office, and the resistance in the other Y_1 must be kept about equal to the resistance of the western circuit from a_1 to the ground at the western office. Ordinary relays R and R_1 and standard transmitters T and T_1 are used. The main-line batteries are shown at B and B_1 and the local batteries at V and V_1. The connections are so clearly shown that it seems unnecessary to enumerate the various circuits. The principle of this repeater consists in holding the sending circuit closed at the repeater by substituting in the place of the receiving line at the instant the latter is opened, a resistance equal to the receiving-line

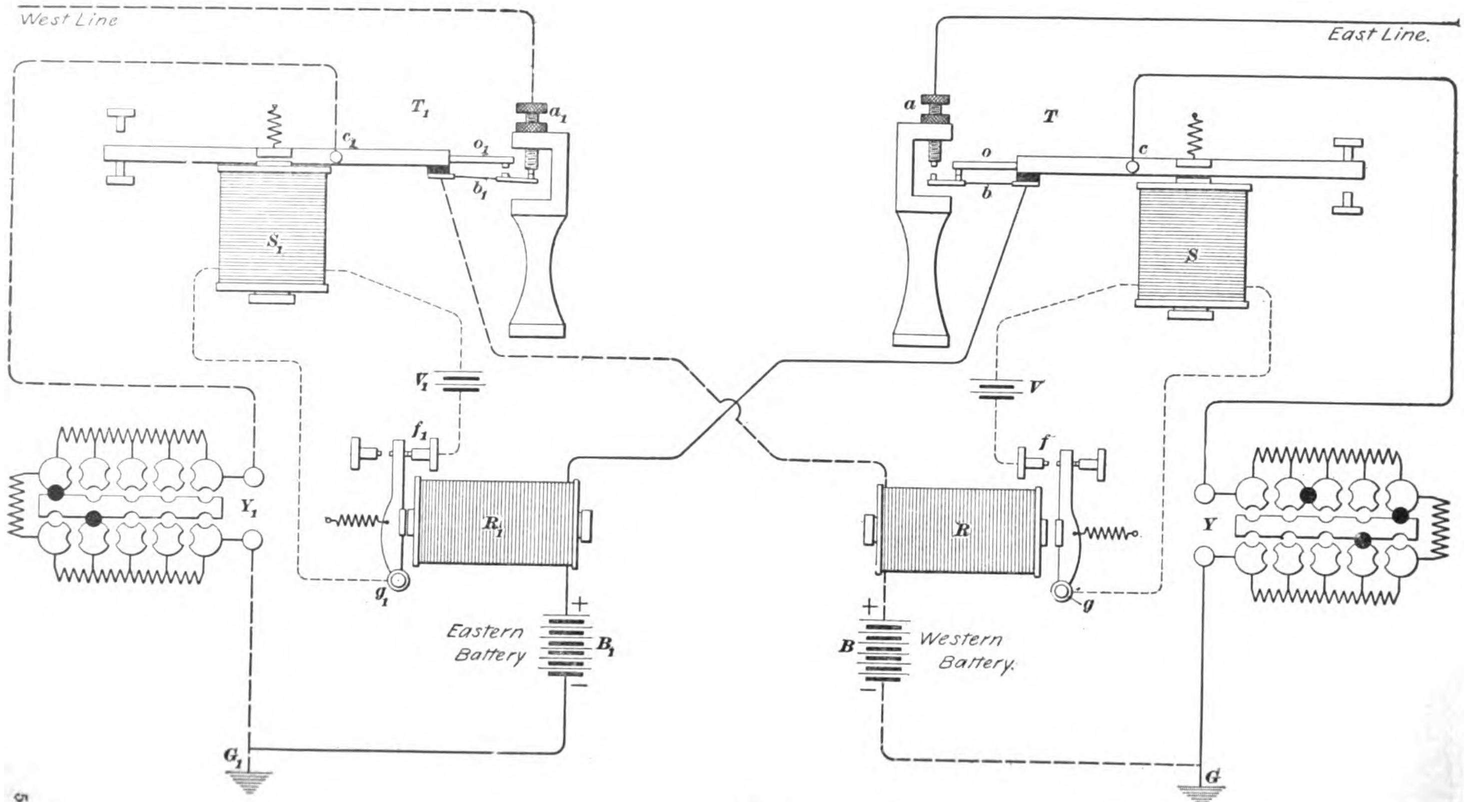

West Line
East Line.
T_1
a_1
c_1
o_1
b_1
S_1
V_1
f_1
Y_1
R_1
g_1
Eastern Battery
B_1
G_1
T
a
o
c
b
S
V
f
Y
R
g
B
Western Battery.
G

FIG. 6

circuit, thus keeping the relay and transmitter that control the sending line closed.

20. Operation of Toye Repeater.—Suppose all circuits to be closed. Then contact a_1 presses against tongue b_1 and holds the circuit open between contacts b_1 and o_1. Similarly, contact a closes the circuit with the tongue b and keeps contacts b and o separated. When the western operator opens his key, there will be no current from the western office through $a_1-b_1-R-B-G$. This will allow the relay R to demagnetize and open the local circuit $V-S-g-f$ at f, and, in turn, allow the transmitter T to open the eastern circuit at a. But just the instant before the tongue b separates from contact a it touches contact o, and, thus, the current, which previously flowed from the main-line battery B_1 through R_1-b-a to east line and through the ground to G_1, and back to the battery B_1, now flows from the battery B_1 through $R_1-b-o-c-Y-G$ to ground to G_1 and back to the battery B_1. These two circuits being of equal resistance and the rheostat circuit Y being instantly substituted for the eastern circuit by the opening of the transmitter T, the relay R_1 is not only not demagnetized, but the strength of the current remains the same, and, consequently, the local circuit of the relay R_1 is kept closed and the western circuit is therefore not opened at a_1. When the western key is closed, current again flows through the relay R, and then through the transmitter S, and all circuits are again closed, which is their normal state. Thus the western circuit repeats into the eastern. To repeat from the eastern into the western circuit, the foregoing actions are reversed.

21. Advantages of Toye Repeater.—The special advantages of the Toye repeater are its extreme simplicity and the fact that it requires comparatively few pieces of only standard apparatus, namely, standard transmitters, relays, and rheostats. However, this repeater is very severe on the main batteries, for they are kept closed all the time. Furthermore, each rheostat must be kept adjusted so that its resistance is about equal to that of the main-line circuit which it replaces, otherwise the difference in the magnetic strength of the relay,

due to shifting the battery circuit from the line to the rheostat, may throw the relay out of adjustment and so open one of the circuits at the transmitter that the relay controls. This means that for efficient service, every change in the weather or resistance of the wire will require an alteration in the value of the rheostat in addition to the usual care of the relay itself, a feat not easily accomplished in extreme weather or on a wire from which there is very much leakage.

22. The Toye repeater is adjusted by varying the resistance in the rheostat until the magnetic pull of the relay is the same whether its circuit is closed at the opposite transmitter through the line or the rheostat. The Toye repeater, without modifications, is not suitable for a side-line repeater, nor is it as satisfactory for all-around work as the Milliken, the Neilson, or the Weiny-Phillips, and perhaps some other modern types. Where a number of short lines have approximately the same resistance, such as the duplex loops, or legs, in the larger cities, the Toye repeater, slightly altered and called the *defective loop repeater*, gives excellent service as a side-line repeater.

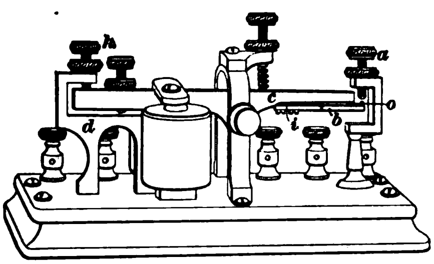


Fig. 7

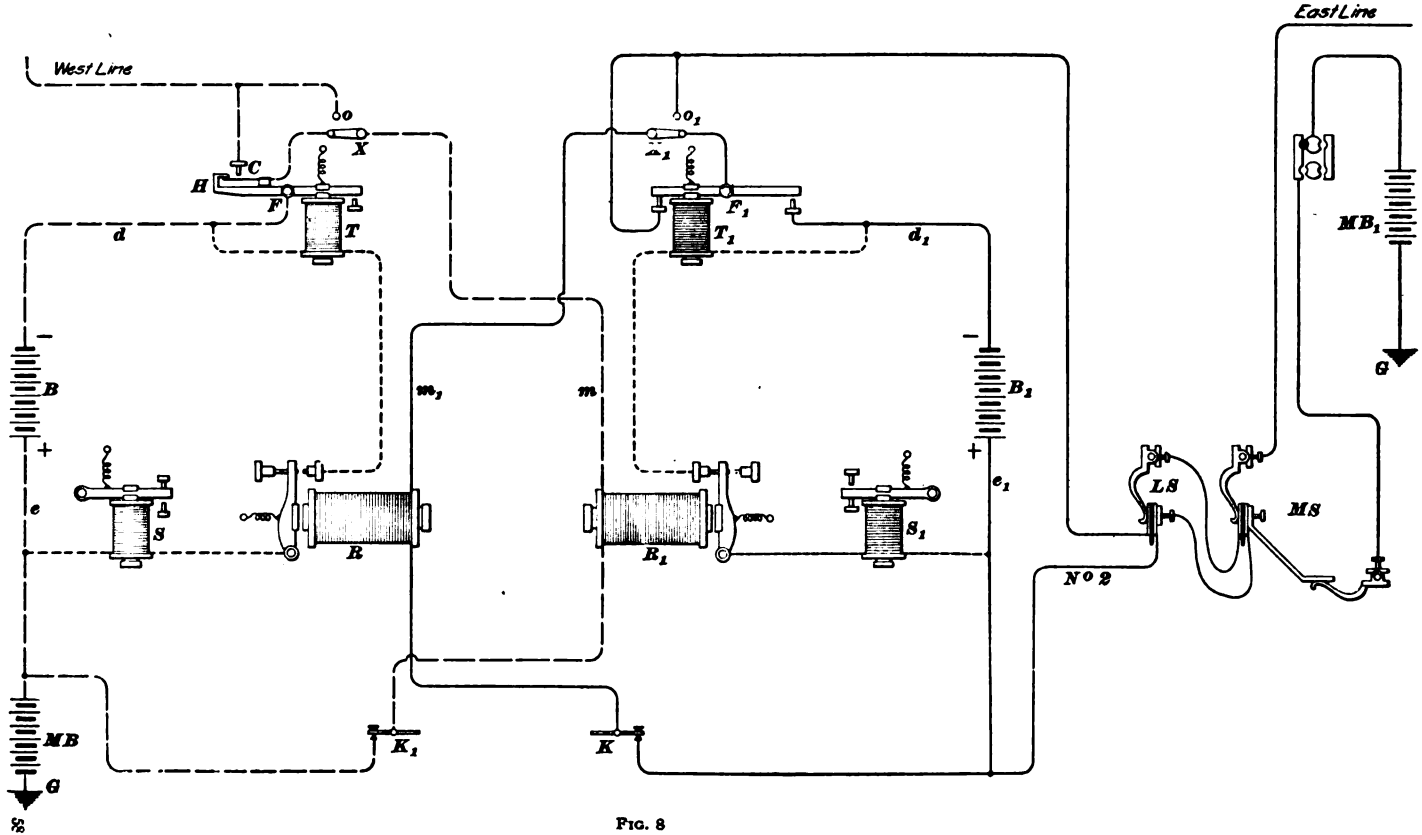
23. Bunnell Transmitter.—A form of transmitter made by Bunnell & Co. that may be used in the Toye and other repeaters, and in some multiplex systems, is shown in Fig. 7. The tongue *b* is fastened to a piece of insulating material *i*, which is in turn secured to the lever *c*. When the magnet releases the armature, a metal contact point on the end of the lever *c* comes in contact with the tongue *b* and presses the latter away from the contact screw *a*. When the armature is attracted by the magnet, the tongue *b* touches the screw *a* just before the contact point on the tip of the lever separates from the tongue *b*. It is, therefore, a continuity-preserving

transmitter, because one circuit is closed before the other is opened. Contacts *a*, *b*, and *c* are connected to separate binding posts on the base of the instrument. If this transmitter is used in the *Atkinson* repeater, which will be described later, it is only necessary to insulate the tip of the screw *h* so that it cannot make a metallic contact with the lever *c*, and, also, to connect the metal piece *d* to a separate binding post upon the base.

24. Modification of the Toye Repeater.—The repeater shown in Fig. 8 was explained in The Telegraph Age by Mr. R. J. Hewett. Although the rheostat, the distinctive feature of the Toye, is eliminated, still it is called a modification of that repeater. All that is necessary to fit out a full set of repeaters are two common relays R and R_1, two transmitters, or two pole changers, or one transmitter and one pole changer T and T_1, two 2-point table switches X and X_1, two keys K and K_1, and two auxiliary batteries B and B_1 of about 7 cells each. Two sounders S and S_1 had better be used as reading sounders, for their use will allow the transmitters to be adjusted closely, so as to reduce their mechanical lag to a minimum.

"Pole changers may be used instead of transmitters. This is shown on the right of the diagram. The stroke of the pole changer T_1 should, however, be shorter than when it is used in regular quadruplex service, so as to reduce the no-current interval, which occurs when the lever F_1 of the pole changer is moving from one position to another, to a minimum; and, since the no-current interval is, in this case, not accompanied by a reversal of current, as in regular quadruplex service, there is no excessive sparking and no difficulty in maintaining a close adjustment. It, therefore, makes a very close breaking repeater, being equally as close as the Neilson repeater."

25. The keys K and K_1 enable the attendant at the repeater office to communicate with either of the two distant operators. The switches X and X_1 are in the proper position for using the apparatus as a repeater. When these switches rest on the contact buttons o and o_1, the relays, sounders, and keys constitute two independent office sets. The eastern circuit is shown connected through the loop switch LS and the main switchboard



West Line
East Line
o
X
C
H
F
T
d
o_1
F_1
T_1
d_1
MB_1
G
B
B_1
e
e_1
S
S_1
R
R_1
m_1
m
LS
MS
No 2
MB
G
K_1
K
58

FIG. 8

MS, one wire being connected to the east line and the other wire through the main-line battery MB_1 to the ground G. The western circuit would be connected through a loop, main switch, west line, and battery in the same manner. The switchboard loop must always connect to the main line in such a way as to have the polarity of the auxiliary battery B_1 agree with the polarity of the main battery MB_1, otherwise there will be a reversal of the current through the relay R when the transmitter or pole changer T_1 opens, and this would cause a kick, or break, in the signals. The kick would result in a vibration of the lever of the relay R. When this occurs, it is only necessary to reverse the wedge at the switchboard to correct the trouble.

As a makeshift, ordinary box relays may be used in place of the transmitter or pole changer. For this purpose, the insulated back contact is supplied with a platinum point, and a third binding post is provided for it. The reading sounder is then omitted, as it cannot be worked in circuit with the high-resistance box relay.

26. Operation of Modification of Toye Repeater. Suppose the eastern operator opens his key; then the relay R, Fig. 8, opens its local circuit, allowing the sounder S and transmitter T to release their armatures and the hook end H of the transmitter T descends and carries with it the spring tongue, thus breaking contact with the stop C and opening the west line. At the same time that the west line is opened at this contact stop C, the spring tongue makes connection with the hook H and this connects the auxiliary battery B in a closed circuit containing the relay R_1 - key K_1 - battery B - wire d - transmitter lever F - hook H - spring tongue - switch X - wire m. The relay R_1 is thus held closed, and, consequently, the transmitter T_1 will be held closed and inactive, and thus prevent breaking back into the sending side.

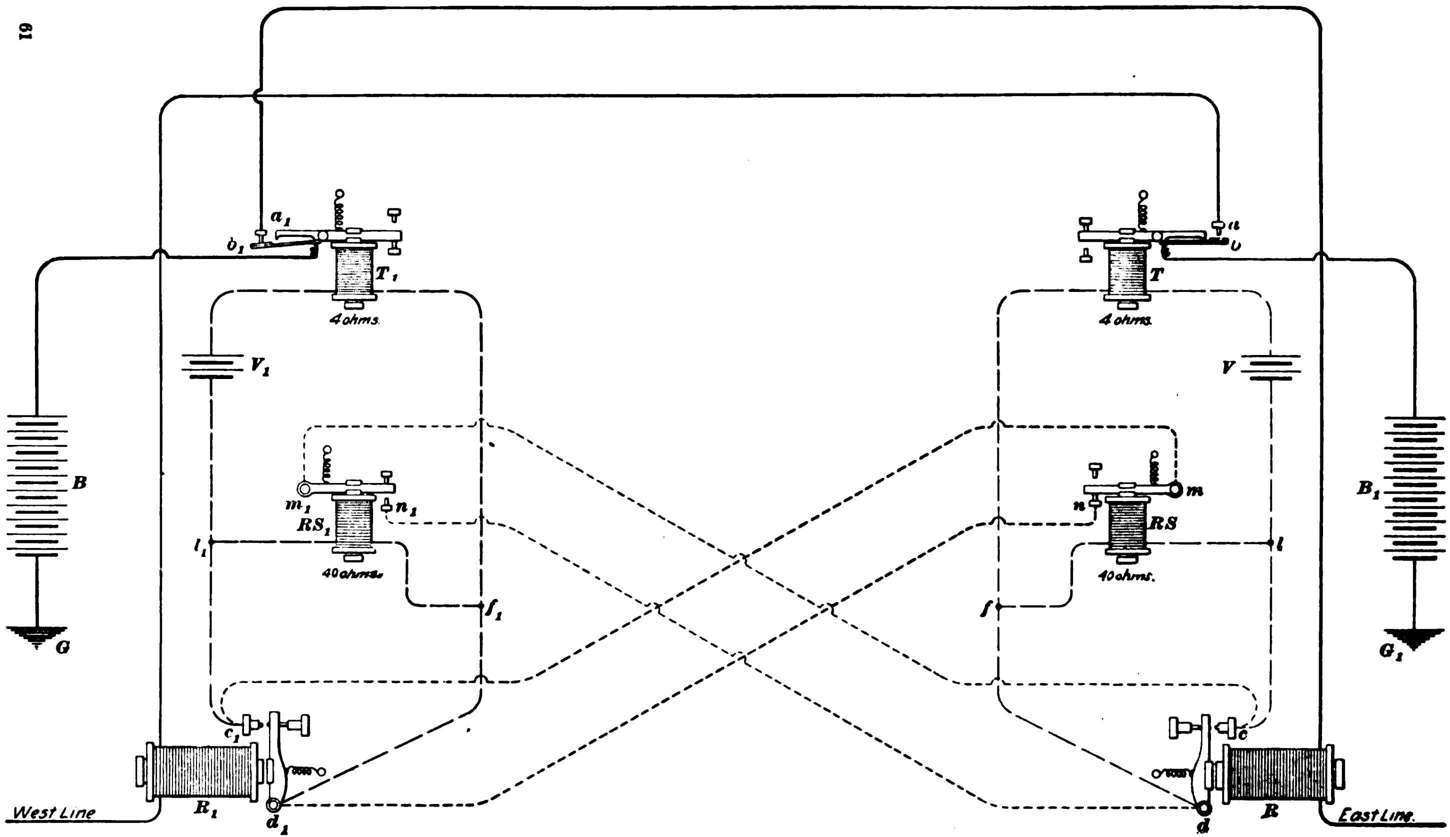
27. When the circuits are idle, the auxiliary batteries supply current to their transmitters and sounders in the usual way, but when the circuits are working, the auxiliary battery on the sending side will supply current to the relay on the

receiving side and hold it closed whenever the receiving side is opened at the transmitter. The auxiliary battery is thus on closed circuit all the time, either on its transmitter and sounder circuit or on the opposite relay. This is all right for gravity cells, because it is better to have them closed too much rather than too little of the time. Having them closed the entire time, however, means considerable consumption of battery material.

NEILSON REPEATER

28. The **Neilson,** or **Neilson shunt repeater,** as it is also called, has given entire satisfaction in Canada. It was the standard repeater of the Western Union at one tine, but was superseded by the Atkinson. It has an advantage over some other repeaters in that it requires only one local battery for two magnets. It may also be used as a side-line repeater. Fig. 9 shows the connections of the Neilson repeater, in which R and R_1 are ordinary relays; RS and RS_1, repeating sounders, of 40 ohms resistance each; B and B_1, main-line batteries; V and V_1, local batteries of 4 cells each; and T and T_1 are either ordinary transmitters or repeating sounders, of 4 or 6 ohms resistance each. Where the local circuits are supplied from a 6-volt dynamo, a 12-ohm non-inductive resistance is connected in series with each transmitter and 75-ohm repeating sounders are used in place of the 40-ohm repeating sounders.

29. When current flows in the two main-line circuits, the armatures of the relays R and R_1, Fig. 9, hold the local circuits closed at c and c_1 and, consequently, currents flow through the two local circuits $V-T-f-d-c-l-V$ and $V_1-T_1-f_1-d_1-c_1-l_1-V_1$. These currents energize the transmitters T and T_1, and keep the two main-line circuits closed at the contact points of the transmitters, the eastern circuit being closed at b_1 and the western at b. In this condition the magnet coils of the repeating sounders RS and RS_1 are short-circuited or shunted by the relay armatures, which have practically no resistance when compared to the 40 ohms in the repeating sounders, and, therefore, practically no current flows through the repeating



a_1
b_1
T_1
4 ohms.
V_1
B
m_1
n_1
RS_1
l_1
40 ohms.
f_1
G
c_1
R_1
d_1
West Line
a
b
T
4 ohms.
V
m
n
RS
l
40 ohms.
f
B_1
G_1
c
R
d
East Line.

FIG. 9

sounders. Consequently, the contact points n and n_1 at the repeating sounders are normally open. In this conndition of the local circuits, the transmitters get $\frac{4}{4+8}=\frac{1}{3}$ ampere, assuming each cell to have an electromotive force of 1 volt and an internal resistance of 2 ohms.

Suppose the circuit through the relay R is opened; then its armature opens the circuit at c, thus removing the short circuit around the repeating sounder RS and leaving the transmitter T and the repeating sounder RS in series. The current from the battery V will now flow in the circuit $V-T-f-RS-l-V$. The current in this circuit is $\frac{4}{40+4+8}=\frac{1}{13}$ ampere, which is not enough to keep the transmitter T closed, but is sufficient to close the 40-ohm repeating sounder RS because it has so many more turns of wire in its coils than there are in the 4-ohm transmitter coils.

With the transmitter T open and the repeating sounder RS closed, should the repeating sounder RS_1 on the other side by any means close, the repeating sounder RS will be again short-circuited, although this time through $f-d-n_1-m_1-c-l$, instead of through $f-d-c-l$, as before. Still the result will be the same. The sounder RS will open and enough current will flow through the transmitter T to close it. This must not occur; that is, one sounder RS_1 must not close nor the other RS open while the eastern key is open. Furthermore, the repeating sounder RS_1 must never close while the eastern circuit is repeating into the western.

30. Operation of Neilson Repeater.—The two main circuits will normally be closed, causing the two transmitters to be closed and the two repeating sounders to be open. Suppose the eastern key is opened. There now being no current through the relay R, it will release its armature and thus open the short circuit around the sounder RS at c. This will leave the repeating sounder RS in series with the transmitter T, causing the sounder RS to close and the transmitter T to open at the same moment. The opening of the transmitter T opens

the western circuit at a, allowing the relay R_1 to demagnetize, and to open its local circuit at c_1. Furthermore, as soon as the transmitter T opened, the repeating sounder RS closed, thereby closing the short circuit $f_1-d_1-n-m-c_1-l_1$ around the sounder RS_1, thus preventing the closing of the sounder RS_1 or the opening of the transmitter T_1, and so preventing the opening of the east line at b_1. Thus, when the eastern key is opened, the east-line circuit is not opened at the repeater.

31. When the eastern key is closed, current will flow from the positive pole of the main battery B through b_1-a_1-R to east line, to the eastern office, the ground, and back through the ground to G and to the negative pole of the battery B. This will energize the relay R and so close the local circuit at c, allowing $\frac{1}{3}$ ampere to flow through the circuit $V-T-f-d-c-l-V$ and causing the transmitter T to close the west-line circuit at a. The repeating sounder RS, being short-circuited by the armature of the relay R, loses its magnetism and, consequently, opens at n the short circuit $f_1-d_1-n-m-c_1-l$ around the sounder RS_1, but at the same instant, since the relay R_1 is now magnetized, the other short circuit, $f_1-d_1-c_1-l_1$, around the sounder RS_1 is closed at c_1. Thus the current through the transmitter T_1 remains the same, $\frac{1}{3}$ ampere, and the transmitter T_1 is kept closed and the sounder RS_1 open, that is, demagnetized, no matter whether the east line is open or closed. Consequently, the transmitter T_1 remains closed all the time that the eastern circuit is repeating into the western—the essential feature of a repeater. To repeat from the western into the eastern circuit, the above operations are reversed. In the Neilson repeater, the local batteries are closed all the time and furnishing the maximum current, $\frac{1}{3}$ ampere, except when the eastern or western key is open in the act of sending a space.

REPEATING SOUNDER

32. By providing an ordinary sounder with contact points, so that the movement of the lever opens and closes a second circuit entirely distinct from the circuit containing the sounder

coils, a **repeating sounder** is obtained. Such a repeating sounder, often called the **quadruplex repeating sounder** because it was probably first used in quadruplex systems, is shown in Fig. 10. It is similar to the ordinary sounder made by the Western Electric Company. It has two platinum or hard-silver contact points, one on the top of the post *u* and one on the bottom of the screw *i*. The circuit is opened and closed between these two points. It also has two extra binding posts *e* and *f*. One of these binding posts is connected to the post *u*, which is insulated from all other metal parts of the sounder, and the other is connected through the lever *l* to the screw *i*.

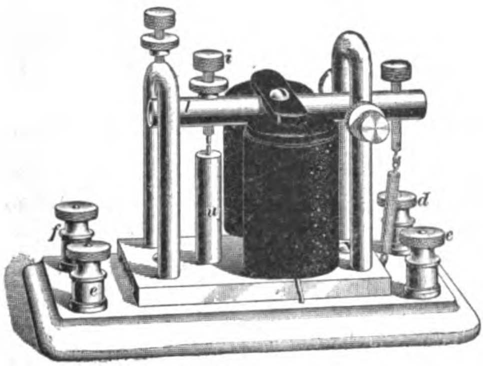


FIG. 10

33. Spring Contact Repeating Sounder.—Another form of repeating sounder, which resembles the ordinary sounder made by Bunnell & Co., is shown in Fig. 11. It has a flat spring, or tongue, *a* at one end of the lever *c* where the second circuit is opened and closed when the lever vibrates down and up. For this reason it is known as the **spring-contact repeating sounder.** The screw *i* and its supporting post *u* are insulated from all other metal parts, except one binding post to which they are connected. The tongue *a* is connected through the lever to which it is

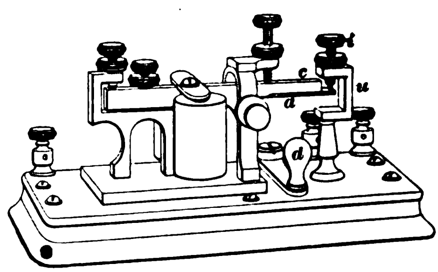


FIG. 11

fastened to a separate binding post. By means of the switch *d*, the circuit may be permanently opened. The Western Electric Company, also, make a repeating sounder similar to their regular sounder, but with a spring tongue.

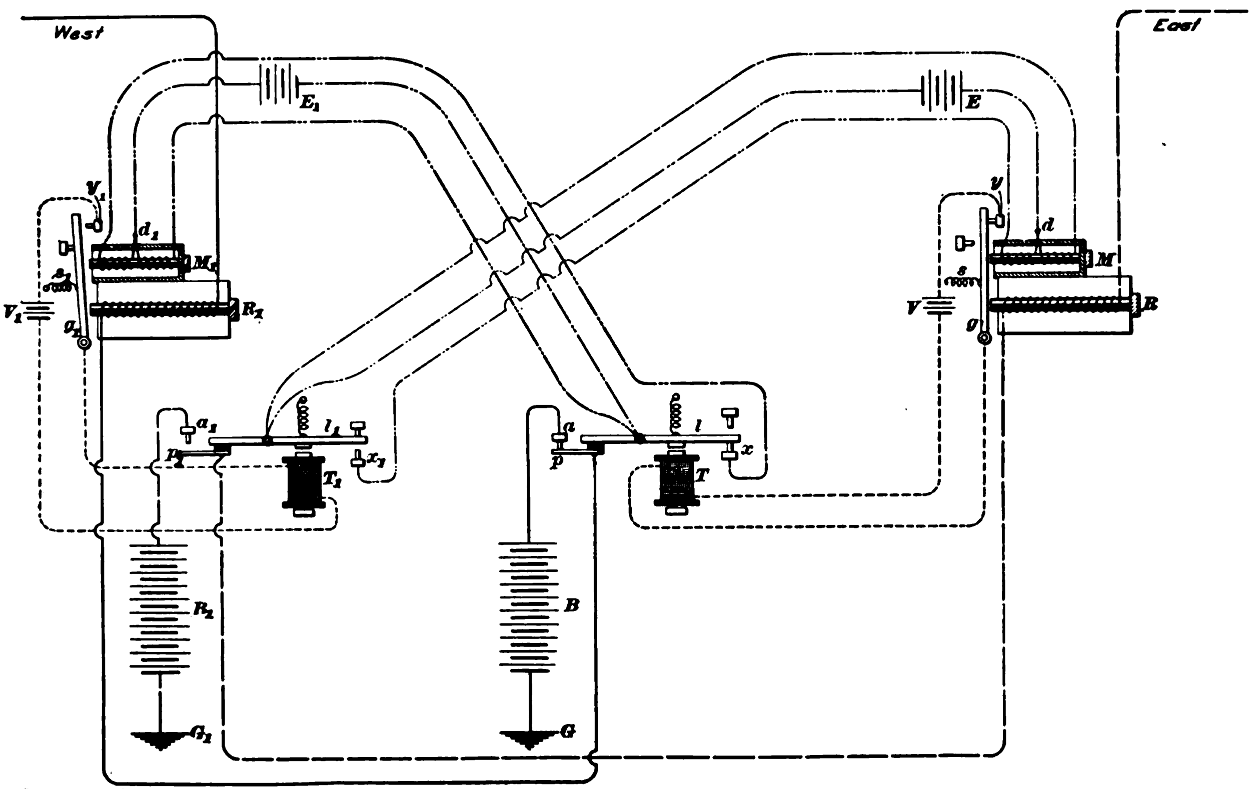
Spring-contact repeating sounders are sometimes called **cushion sounders** because the spring eliminates the jar or rebound that occurs when a solid bar strikes a fixed contact point.

34. When a repeating sounder or relay is used merely for the purpose of shunting a local circuit, as in some single-line repeaters, the contact points should be very close together in order that the sounders will act quickly. Also, quite a strong tension should be given the spring so as to make a good contact and firm signals. On the other hand, when a repeating sounder or relay is used in connection with a neutral relay on a quadruplex circuit, the contact points of both the neutral relay and the repeating sounder or repeating relay should be sufficiently far apart to give the levers considerable play. The effectiveness of the repeating devices depends, in this case, on the space between the contact points of both the neutral relay and the repeating instrument being too great for a feeble discharge current from the line to force the levers entirely across the space between the stops. This is a point too frequently overlooked by those having charge of quadruplex apparatus.

WEINY-PHILLIPS REPEATER

35. The **Weiny-Phillips repeater,** used by the Postal Telegraph-Cable Company, the United Press, Great Western Railway Company, and probably others, is shown in Fig. 12. Here T and T_1 are transmitters; B and B_1, the main-line batteries; V and V_1, the local batteries that operate the transmitters; E and E_1, extra local batteries in circuit with the extra magnets M and M_1; and R and R_1 are the main-line relays.

By means of the extra magnets and extra local batteries, the continuity of the line that is repeating into the other line is preserved. In this respect, it somewhat resembles the Milliken



West
East
E_1
E
V_1
v_1
d_1
M_1
R_1
s_1
g_1
V
v
d
M
R
s
g
a_1
p_1
l_1
x_1
T_1
a
p
l
x
T
R_2
B
G_1
G

Fig. 12

repeater, except that the extra magnet does not have a separate armature lever of its own, but acts directly on the lever of the line relay above which it is placed. This extra magnet is made quite different in shape and construction from the ordinary electromagnets used in ordinary relays and sounders. It has but one coil, which is enclosed in a soft-iron cylinder, open at the front and closed at the rear except for a hole at the center through which the iron core may project. In the ordinary relay magnet, the path of the lines of force is through one iron core–yoke–other iron core and armature back to the first iron core, thus completing the circuit. In

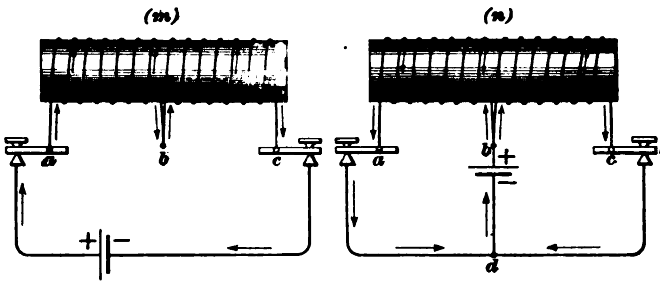


FIG. 13

this magnet the path of the lines of force is through the iron core–the rear-end iron plate–sides of iron cylinder and armature back to the iron core from which they started.

36. Differentially Wound Magnet.—The winding and construction of the extra magnet is the distinctive feature of the Weiny-Phillips repeater. It contains two coils of the same number of turns and resistance. The end of one coil and the beginning of the next are joined together and connected to a binding post on the base of the instrument. In Fig. 13 is shown an iron core over which two coils are wound in this manner. If a battery is connected between the first, or inside, end of one coil, and the last, or outside, end of the second coil, as shown in (*m*), the current will flow through both coils in the same direction around the iron core, and will therefore magnetize it as usual in any relay. But if the battery is connected as shown in (*n*), the current from the positive pole of

the battery will divide into two parts at b, one flowing in the right-hand coil around the iron core in one direction, the other flowing in the left-hand coil, but in the opposite direction around the iron core. Consequently, the magnetizing forces of the two coils oppose each other, and the magnetism created in the iron core will be due to the difference in these two magnetizing forces. If both coils have exactly the same resistance, the current in each will be exactly equal. Furthermore, if there is also exactly the same number of turns in each coil, the ampere-turns in each coil will be equal but will oppose each other. Consequently, as the resultant magnetizing force of these coils is the difference of two equal opposing forces, it will be zero and the core will not be magnetized at all.

37. However, should the key a, in Fig. 13 (n), be opened, the core will be magnetized in a certain direction because the current now circulates only through the right-hand coil, and, therefore, the magnetizing effect of this coil is not opposed, as before, by that of the left-hand coil, the magnetizing effect of which is now zero. If the key a is closed and the other key c is opened, the core will be magnetized as strongly as before, but in an opposite direction. But as long as the armature is made of soft iron and is not polarized (that is, permanently magnetized) by the presence of a permanent magnet, the core will attract it no matter in which direction the core is magnetized. A magnet having two similar coils of the same number of turns and the same resistance, and connected as shown in (n), is said to be **differentially wound.** This differential method of winding a magnet should be thoroughly understood because many of the present duplex and quadruplex systems, which will be taken up later, would be impossible without differentially wound magnets.

38. When the transmitter T, Fig. 12, is closed, the current from the extra local battery E_1 will flow to d_1, where it divides equally, because the two circuits are equal in resistance, one half flowing through the right-hand coil of the magnet M_1 to the lever l, where it reunites with the other half that flowed through the left-hand coil on M_1, and contact x to l; from which

point the whole current returns to the battery. Hence, when the transmitter is closed, as shown at T, the magnet M_1 is not magnetized and it exerts no attractive force on the armature lever g_1. When the transmitter opens, as shown at T_1, the left-hand coil of M is opened at x_1, and current then flows only through the right-hand coil of M. This energizes the magnet and causes it to pull the armature lever g against the contact stop y, in spite of the spring s.

39. Operation of Weiny-Phillips Repeater.—In the normal condition, all circuits are closed. Suppose the western key is opened, thereby depriving the relay R_1 of current. As current is flowing through both coils of the extra magnet M_1. in opposite directions, the magnet M_1 exerts no attractive force on its armature and, therefore, the armature lever g_1 is pulled away from its contact y_1 by the spring s_1, thus opening the local circuit, containing the battery V_1, and demagnetizing the transmitter magnet T_1. This allows the transmitter T_1 to open, at x_1, the circuit through the left-hand coil of the extra magnet M, thereby allowing the right-hand coil to energize the magnet M. This magnet M will, therefore, hold the armature lever g against the stop y, when, a moment later, the eastern circuit is opened at p_1, and so cuts off all current from the relay R. Thus the opening of the local circuit containing the transmitter magnet T is prevented, thereby preserving the continuity of the western circuit between contacts p and a and, also, preventing the magnet M_1 from being energized and attracting its armature lever g_1. Therefore, the eastern circuit remains open as long as there is no current in the western line and relay R_1. As soon as the western key is closed, the relay R_1 will be magnetized, thereby attracting the lever g_1, and closing at y_1 the local circuit through $V_1 - y_1 - g_1 - T_1$. This in turn closes at p_1, the eastern circuit through $R - p_1 - a_1 - B_1 - G_1$ and the ground back to the eastern office; it also closes at x_1 the extra local circuit containing the left-hand coil on the magnet M, thus allowing the lever g to be held in contact with y by the relay R alone. Thus all circuits are again in their normal condition, that is, closed. The operation of repeating from the

eastern into the western circuit is the reverse. Two local circuits may be supplied from the same battery, that is, E_1 and V_1 may be replaced by one battery and E and V by another battery.

40. Arrangement of Weiny-Phillips Repeater With Dynamos.—The connections for the Weiny-Phillips repeater, where dynamos are used instead of primary cells, are shown in Fig. 14. All four local circuits are supplied from one dynamo D_1 and the two main lines from another dynamo D. The little circles represent the binding posts on the base of the instruments; L, L_1, L_2, L_3, L_4, and L_5 are lamps, or non-inductive resistance coils, of the proper resistance to allow the desired current to flow in their respective circuits.

On the base of each transmitter there is a switch, w and w_1. With these switches in the positions shown, that is, one switch w connecting contact b with e and the other switch w_1, connecting contact b_1 with e_1, the apparatus is properly connected to automatically repeat in either direction, the same as shown in Fig. 12, but with dynamos substituted for primary cells. With the switches in the positions shown, the various circuits may be traced as follows: The western circuit is from the west line through the jacks at the main and loop switchboards $- k_1 - R_1 -$ eastern transmitter-tongue $p -$ contact stop $a -$ loop and main switchboards $-$ lamp $L_1 -$ dynamo D and ground plate G, to the western office and west line. The eastern circuit is from the east line through the jacks at the main and loop switchboards $- k - R - p_1 - a_1 -$ loop and main switchboards $- L - D - G$ and back through the ground to the eastern office and east line. The circuit through the magnet t_1 of the western transmitter may be traced from D_1 through $V_1 - L_2 - y_1 - g_1 - t_1 - V - D_1$. The circuit through the magnet t of the eastern transmitter may be traced from D_1 through $V_1 - L_4 - t - g - y - V - D_1$. The extra local circuit through one extra magnet M_1 is from $D_1 - V_1 - L_3 - d_1$, at which point the current divides into two equal parts, one part going through the right-hand coil on the magnet M_1 to $c - b - e - V - D_1$, the other part going through the left-hand coil on the magnet M_1 to $x - c - b - e - V - D_1$. The extra local

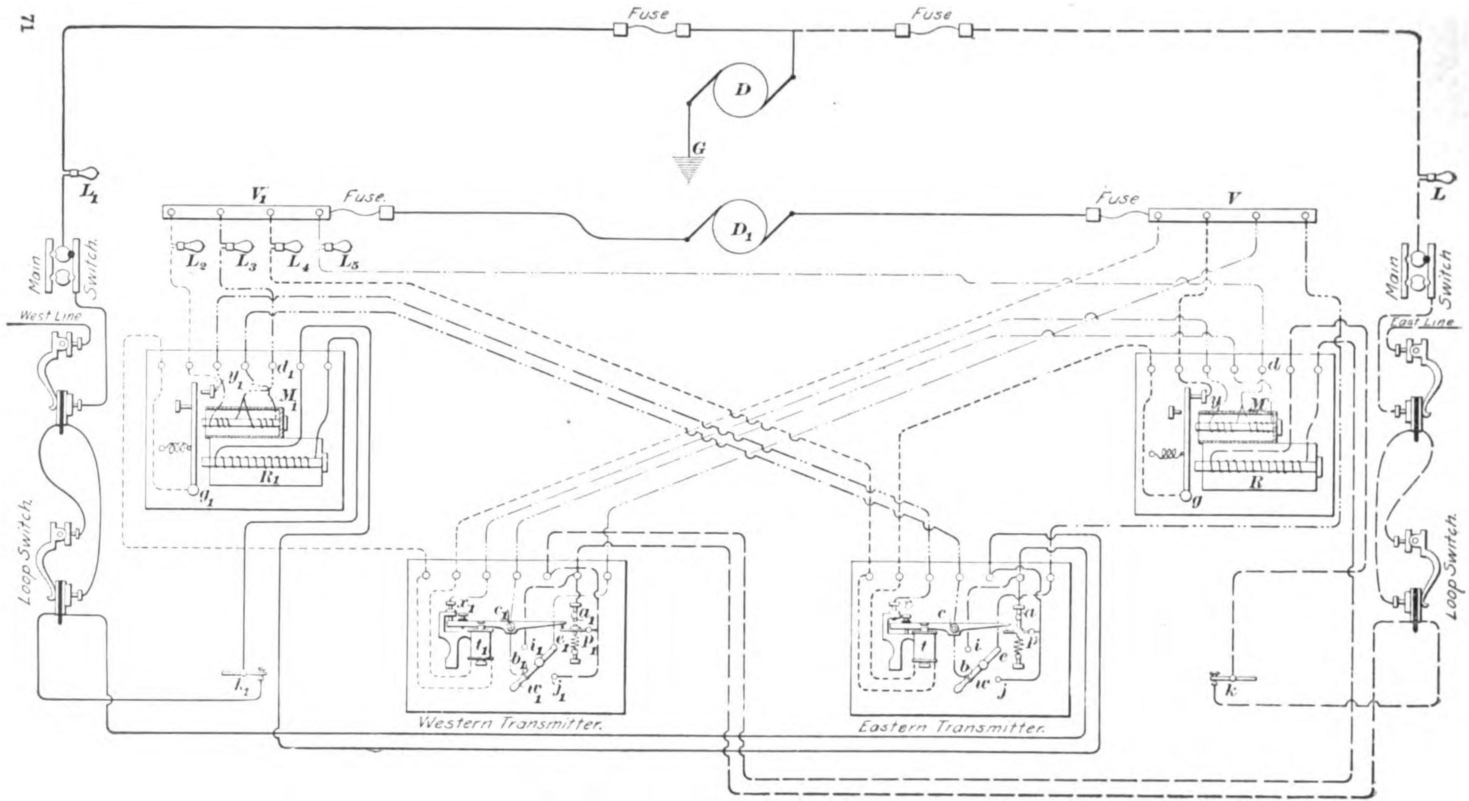

Fuse
Fuse
D
G
D_1
Fuse.
Fuse
V_1
V
L_1
L
L_2
L_3
L_4
L_5
Main Switch.
Main Switch
West Line
East Line
Loop Switch.
Loop Switch.
y_1
d_1
M_1
R_1
g_1
y
M
d
R
g
k_1
k
x_1
c_1
a_1
e_1
p_1
t_1
i_1
b_1
w_1
j_1
c
a
t
i
p
e
b
w
j
Western Transmitter.
Eastern Transmitter.

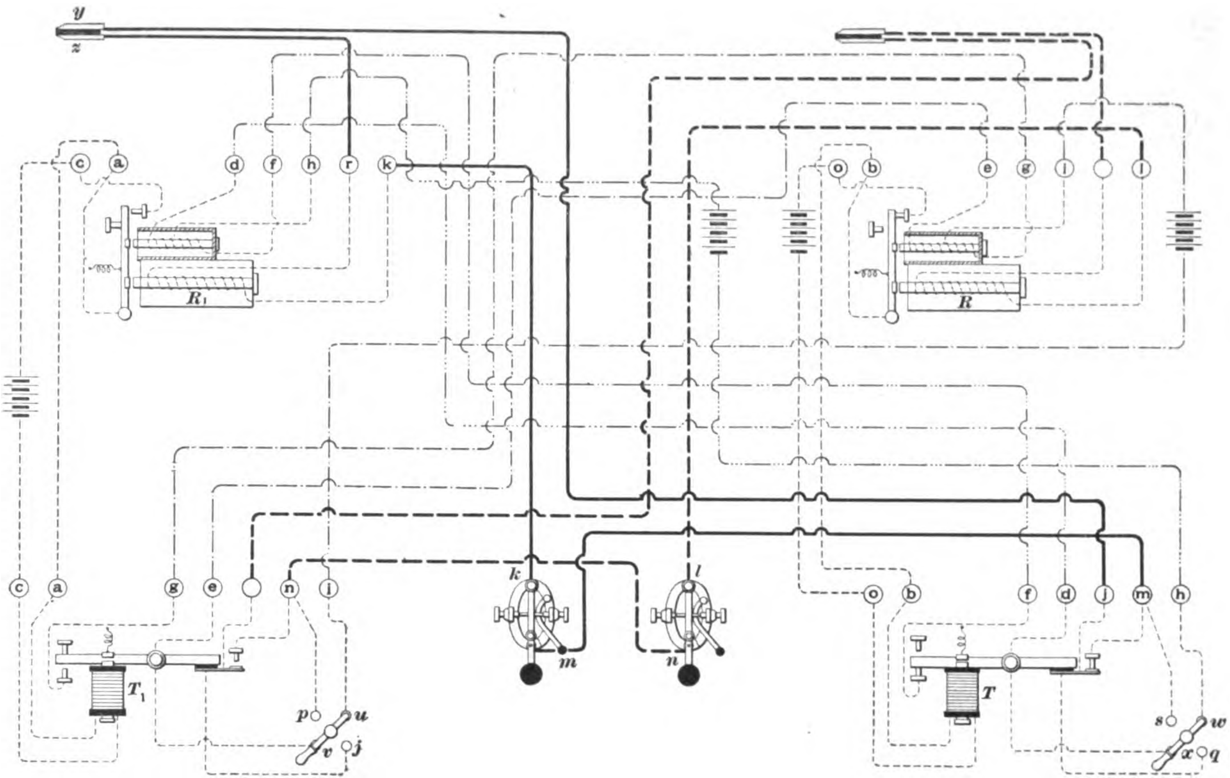
FIG. 14

circuit through the other extra magnet M is from D_1 through V_1-L_5-d, at which point the current divides into two equal parts, one part going through the right-hand coil on the extra magnet M to $c_1-b_1-e_1-V-D_1$, the other part going through the left-hand coil on the extra magnet M to $x_1-c_1-b_1-e_1-V-D_1$. The repeating operation is exactly the same as that explained in connection with Fig. 12.

41. By shifting the switch w so as to disconnect contacts e and b and to connect contacts i and j, the current is cut off from both coils of the extra magnet M_1, and the western main-line contact points p and a on the eastern transmitter are short-circuited. This enables the western transmitter to be used as a simple sounder for the relay R_1 and, moreover, the western line still repeats into the eastern line, but the eastern cannot repeat into the western circuit. The reverse is the case when switch w_1 is turned to connect contacts i_1 and j_1, and switch w is in its present position connecting contacts b and e. When both switches are turned so as to connect contacts i and j and contacts i_1 and j_1, the eastern and western line circuits may be used independently of each other, the transmitters acting merely as sounders.

42. Local Circuits Operated by Batteries.—In Fig. 15 is shown the Weiny-Phillips repeater with its local circuits operated by batteries, as wired in offices of the Postal Telegraph-Cable Company. Binding posts similarly lettered are connected together; in some cases, where shown, a battery is included in the circuit between two similarly lettered binding posts. This method of designating binding posts that are connected together with the same letter or number is extensively used, especially by the Postal Telegraph-Cable Company. The small holding coil on each relay has a resistance of 10 ohms when batteries are used for operating the repeater.

43. Local Circuits Operated by Dynamos.—In Fig. 16 is shown the wiring of the Weiny-Phillips repeater with all local circuits operated from one 40-volt dynamo. A non-inductive resistance coil of 180 ohms is included at o, s, x, and n in each



2 West

Fig. 15

2 East

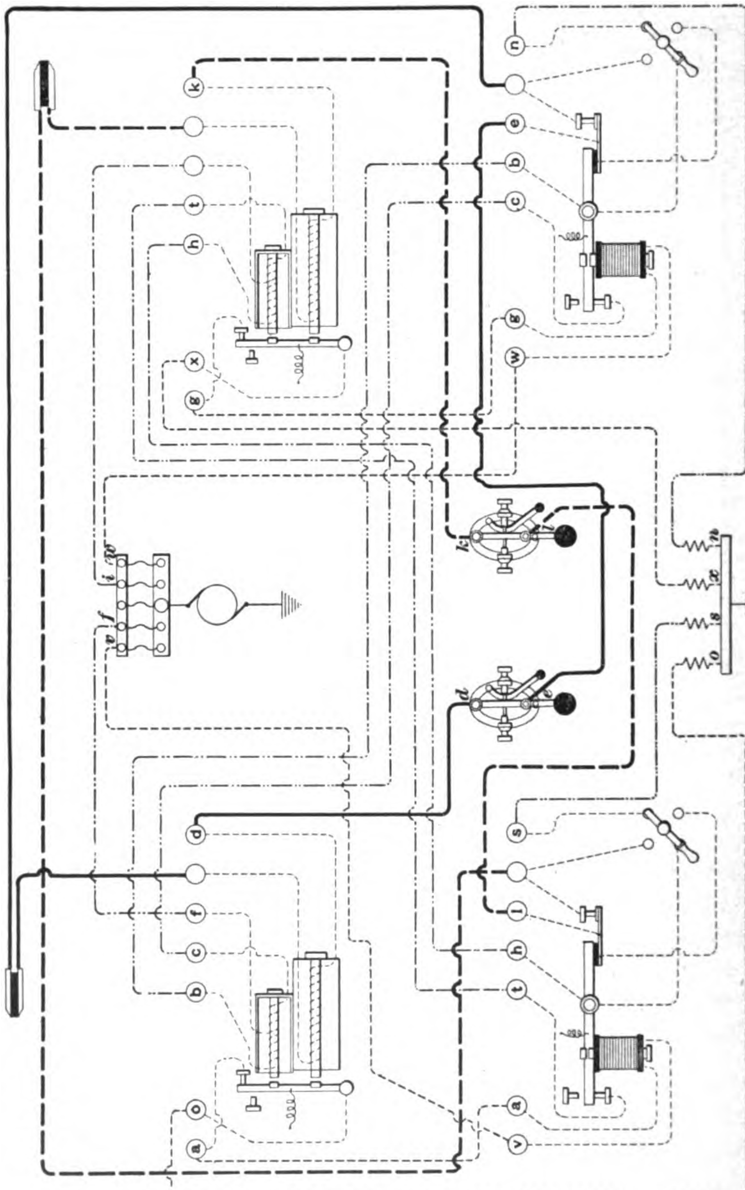


Fig. 16

local circuit to limit the current strength; it also reduces the time constant of the circuit and hence reduces the retarding effect due to the inductance of the magnet coils. For use with a 40-volt dynamo, the holding coil is wound to a resistance of 20 ohms.

44. In Fig. 17 is shown the Postal Telegraph-Cable Company's combination Weiny-Phillips repeater with local circuits operated by a 40-volt dynamo. With the switches *A*, *B*, *C*, and *D* thrown to the right, the apparatus is connected as a main-line repeater; with the switches thrown to the left, two half repeaters are formed. The binding posts marked *Jack 1, MB* and *Jack 1A, MB* connect through the two sides (*1* and *1A*) of one jack, say No. 1, on the main switchboard to one main line and one main-line battery or dynamo, while the posts marked *Jack 2, MB* and *Jack 2 A, MB* connect through the two sides of another jack, say No. 2, on the main board to the other main line and main-line battery or dynamo. The binding posts marked *SSLB 1* and *SS LB 1A* may be used, when the switches are turned to the left, to extend the local sending circuit containing the sounder S_2 and key K_2, which is now controlled by the relay R_1, to another office or another part of the same room, a source of current being included in the circuit where most convenient. The binding posts marked *SS LB2* and *SS LB 2 A* may be used for a similar purpose, when the switches are turned to the left. The binding posts marked *RS LB1*, *RS LB1 A*, *RS LB2*, and *RS LB2A* may be used in a similar manner, when the switches are turned to the left, to extend the receiving circuits containing the magnets of the transmitters T_2 and T_1 to other parts of the same office or to other offices in the same city, sources of current being included in the circuits where most convenient.

45. In 1912, the Postal Telegraph-Cable Company made some improvements in the Weiny-Phillips type of repeater consisting in the use of so-called *noiseless transmitters* in place of the sounding transmitters and changes in the construction of the relays. No change in the principle of the repeater is involved and the instruments are interchangeable with those

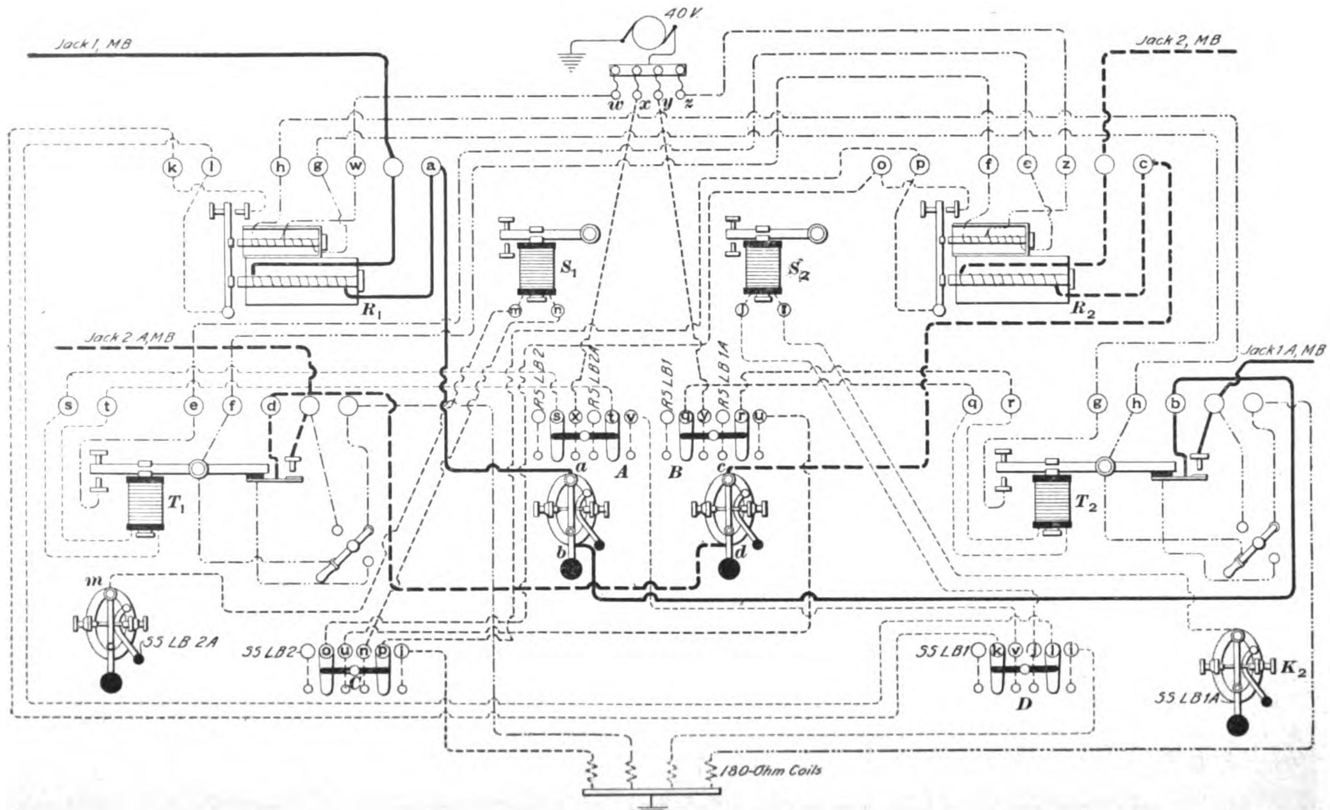

40 V.
Jack 1, MB
Jack 2, MB
Jack 2 A, MB
Jack 1 A, MB
w x y z
R1
R2
S1
S2
T1
T2
A
B
C
D
a
b
c
d
m
K2
RS LB 2
RS LB 2A
RS LB 1
RS LB 1A
SS LB 2A
SS LB 2
SS LB 1
SS LB 1A
180-Ohm Coils

Fig 17

previously used, except where the transmitters are used to replace the old style of transmitter, a sounder must be added. A switch is provided for cutting out the sounder when it is not required for reading.

The improved form of relay has the holding magnet, which consists of a pair of coils on separate cores, below the pivot. The construction of the relay is such that it is responsive to signals at very high speeds. The transmitters are of the relay type, all parts being made as light as possible, so that they will respond to rapid impulses.

The resistance of the main-line relay magnets is approximately 250 ohms and of the holding magnets 20 ohms. The resistance of the transmitters, where 40 volts is used, is 20 ohms, and where 110 volts is used, the resistance is 150 ohms. Where 110-volt local circuits are used, 600-ohm resistance coils are connected in series with the holding magnets and 1,500-ohm resistance coils in the transmitter circuits, and the coils are placed next to the fuse block instead of next to the ground as where 40 volts are used. The relay type of transmitter is constructed like a relay, except that it has two tongues or contact springs insulated from each other, two front contact stops, one back stop, and the usual switch on the transmitter base.

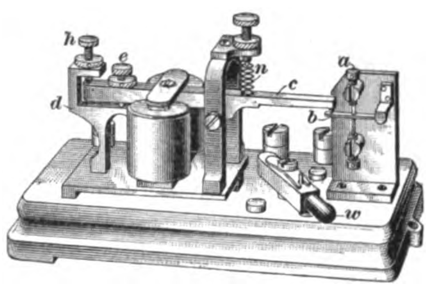


FIG. 18

46. Adjusting the Weiny-Phillips Transmitter. Although the Bunnell transmitter with the tongue insulated at all times from the lever, may be used as a transmitter in the Weiny-Phillips repeater, the Postal Telegraph-Cable Company generally uses the regular Weiny-Phillips transmitter shown in Fig. 18, or the newer relay-type of transmitter used in the 1912 improved Weiny-Phillips repeater. The bar of the transmitter shown in Fig. 18 is made of aluminum to secure

quicker action on account of its smaller weight and inertia, and the tongue *b* does not ever make electrical contact with the bar *c* because to the end of the bar *c* is fastened a piece of insulating material that projects downwards in the path of the end of the tongue *b*. On the base is a switch *u*, the use of which has been explained. The lower end of the screw *h* has a piece of insulating material inserted in it, so that no electrical contact is made between the screw *h* and the bar *c*, except when the bar *c* is held down by the magnet so that the point of the screw *e* touches the piece *d*.

47. To better illustrate the several adjustments, let it be assumed that the transmitter is entirely out of adjustment, although this would, of course, seldom be the case. First the front stop screw *e* should be adjusted so that two thicknesses of ordinary telegraph blanks will pass between the magnet cores and the armatures with the bar held down. When this position is found, firmly tighten the locknut on *e* and, still holding down the bar, adjust the rear contact screw *a* until it depresses the tongue *b* about $\frac{1}{32}$ inch away from the hard-rubber projection on the end of the bar *c*. Make this secure by tightening the locknut on *a*. Now release the bar *c* and adjust the spring *n* on the top of the bar until the bar is rather strongly upheld. Adjust the screw *h* until the distance between the point of the contact screw *a* and the tongue *b* is $\frac{1}{64}$ inch and lock the screw *h* firmly in this position. Note that in the Weiny-Phillips transmitter, the screw *h* has an insulated tip of hard rubber. Using a very fine and very thin file, next file the front contact on the end of the screw *e* and rear contacts on the end of the screw *a* just enough to brighten the surface. The spring *n* on the top of the bar should be adjusted so that there is no lag in either direction when dots are made by the relay armature. That is, the bar should respond very quickly to signals and as quickly return to its open position.

It will be noticed that only $\frac{1}{64}$ inch is allowed between the rear contact *a* in the open position while in the closed position the tongue is $\frac{1}{32}$ inch from the insulated piece on the end of *c*. This arrangement has the effect of slightly lengthening the

duration of the signals and making even a very light sender carry over long distances while a heavy sender is easily passed to the end of the line. It was customary some time ago to secure this result for a light sender by letting down or weakening the spring on the relay; but this is not good practice because if there were even a moderate escape on the wire there would not be sufficient margin and in any case the light sender would have difficulty in breaking.

48. Adjusting the Weiny-Phillips Relay.—As a rule, the *holding*, or third, magnet should be kept close to the armature, and all the magnet cores should be about the same distance from the armature. The tension on the retractile spring should be strong enough to secure quick action without sticking but weak enough to allow the armature to be quickly attracted when the opposite side tries to break. In heavy weather the relay should be adjusted by drawing back the magnets, not by tightening the spring, because, unless the local current is very strong, a strong tension on the spring causes the repeater to rattle.

It will sometimes be difficult to secure an adjustment of the holding coil so as to allow one side to break the other. This may be caused by the holding coil on one relay being non-differential. To ascertain if this is true, throw the switches on the transmitters to the right-hand side; open both keys and turn down the springs on both relays until they just nicely stand open. Still leaving the keys open, throw the switches to the left again. One relay R_1, Fig. 17, should now stand open and the other R_2 closed. With the forefinger press open the relay R_2 that stands closed; this should close the relay R_1 that stood open before and when the finger is removed relay R_2 should still remain open. If this is what occurs, the relay R_2 is all right. Now open the other relay R_1 with the finger and if this causes relay R_2 to close while relay R_1 remains open after the removal of the finger, the repeater is all right and the cause of one side not being able to break is probably due to wire trouble, provided the relay spring as well as the transmitter are properly adjusted.

49. It may, however, frequently occur, especially with low-wound holding coils (6 ohms), that in the test just described one relay refuses to release its armature when the other relay's armature is pressed open. This will indicate that the coil is not magnetically differential, and usually is due to some high resistance in the circuit. As there are but 3 ohms on each half of this holding coil in its normal condition, the slightest looseness of any binding post, or switch, or corroded local points on the transmitter, will introduce a resistance that will bear a large ratio to the total resistance of that half of the circuit and cause the magnetic effect of the two currents to be far from balanced. This can usually be remedied by tightening all connections in the local circuit both under the transmitter and relay as well as the wires in posts. The contacts on the front of transmitters may be filed a very little and care should be taken that the switches make a good, tight clean contact.

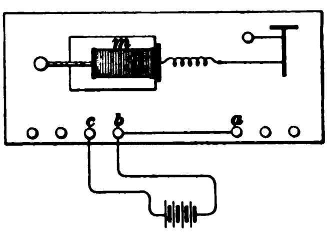


FIG. 19

50. To Test Differential Winding of Relay.—If this does not remove the trouble, the relay in question should be taken out and the third coil tested on a local circuit. This test is made as follows: Using any source of current sufficient to cause strong magnetization of the coil but not sufficient to heat it too much, join the binding post *c*, Fig. 19, which connects with the center of the holding coil, to one battery wire and join the binding post *b*, which is connected to one end of the coil, to the other battery wire. Now, with a short piece of large wire, join binding posts *a* and *b*, thereby connecting the two halves of the winding in parallel. If the spring can be made very weak without the armature closing, the magnet is differential. To secure great exactness, remove the wire from the post marked *c* and weaken the spring until the armature barely stands open. Move up the magnet *m* as close as possible without touching the armature when the latter is held in its closed position. Connect *c* to the

battery again and if the magnet is absolutely magnetically differential the armature will still remain open. Relays having their local coil wound to 50 ohms are not much affected by slight changes of resistance, anything but an absolute opening or burning out and short-circuiting of the winding will have little or no effect.

51. General Rule for Repeating.—A safe rule to follow is never to pass signals that do not reach you clearly. To avoid this when the signals are faulty, throw the switches to the right, thus cutting the repeaters into ordinary relays and adjust each side separately before cutting the wires together again by throwing the switches to left. If the signals are broken up on one side, the wire on that side must be in trouble, provided, of course, there is not another repeater between you and the sender and that the relay spring and magnets have been properly adjusted.

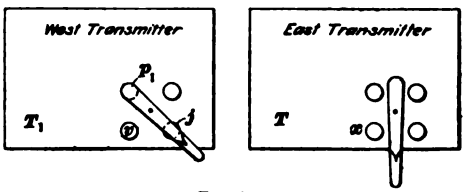


FIG. 20

52. Quick Test of Repeater Points.—When the east is sending and it is desired to determine quickly whether the signals are passing through properly, throw the switches on the Weiny-Phillips transmitters to the positions shown in Fig. 20. The east signals (see also Fig. 12) are now repeated, by the operation of the east relay R and east transmitter T, into the west line. They also operate the west relay R_1, which in turn actuates its transmitter T_1 as a sounder. The eastern sending operator is not interfered with because the east-line points in the west transmitter are short-circuited by the switch on the west transmitter, which connects together points p and j. Furthermore, the extra magnets on both relays are open at points v and x, and hence have no effect on the operation of the two relays.

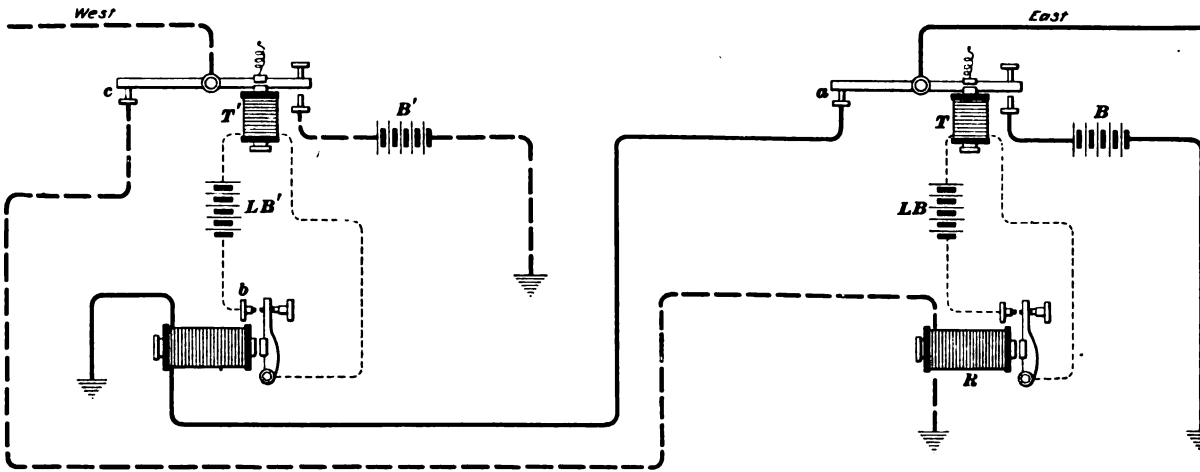


Fig. 21

OPEN-CIRCUIT REPEATER

53. A repeater for use on open-circuit telegraph systems is shown in Fig. 21. No batteries are normally connected to the circuit, but the line is held closed at terminal and repeating stations. The normal positions of the instruments are shown. The western operator starts to send by closing his key, thus connecting a battery at his office between the ground and the west line and thereby causing the relay *R* to close the circuit containing the transmitter *T*, which connects the east line through the battery *B* to ground and sends a current to the eastern station where a relay is closed. The opening of the circuit containing relay *R'* at contact *a* has no effect upon the transmitter *T'* because its circuit was already open at *b*.

To repeat from east to west this operation is reversed. Polar relays may be used in place of the relays *R* and *R'*, in which case a retractile spring is used to hold the polar-relay armatures and the local circuits open when the lines are closed through stops *a* and *c*.

TELEGRAPH REPEATERS

(PART 2)

TELEGRAPH-REPEATER CIRCUITS AND INSTRUMENTS—(Continued)

AUTOMATIC TELEGRAPH REPEATERS—(Continued)

ATKINSON REPEATER

1. The **Atkinson repeater,** shown in Fig. 1, requires two ordinary relays R and R_1, two repeating sounders RS and RS_1, two transmitters T and T_1, two main-line batteries B and B_1, two local batteries V and V_1, and two extra local batteries E and E_1. After the transmitters have once been adjusted and all screws firmly locked in place, they will need no further attention and the repeater can be readily kept in proper order by any operator that is able to adjust an ordinary relay and sounder. This repeater has proved quite successful for this reason. In the normal condition, the two main-line, the two local, and the two extra local circuits are closed, causing the armature levers of all six magnets to be attracted, and all their local contacts to be closed except f and f_1, which are open.

2. Operation of Atkinson Repeater.—The opening of the eastern key will cause the relay R to release its armature. Therefore the local circuit, which contains the local battery V and transmitter T is opened at m, because it is already open at f, and it will remain open as long as the other transmitter T_1 remains closed. Moreover the transmitter T_1 will not be

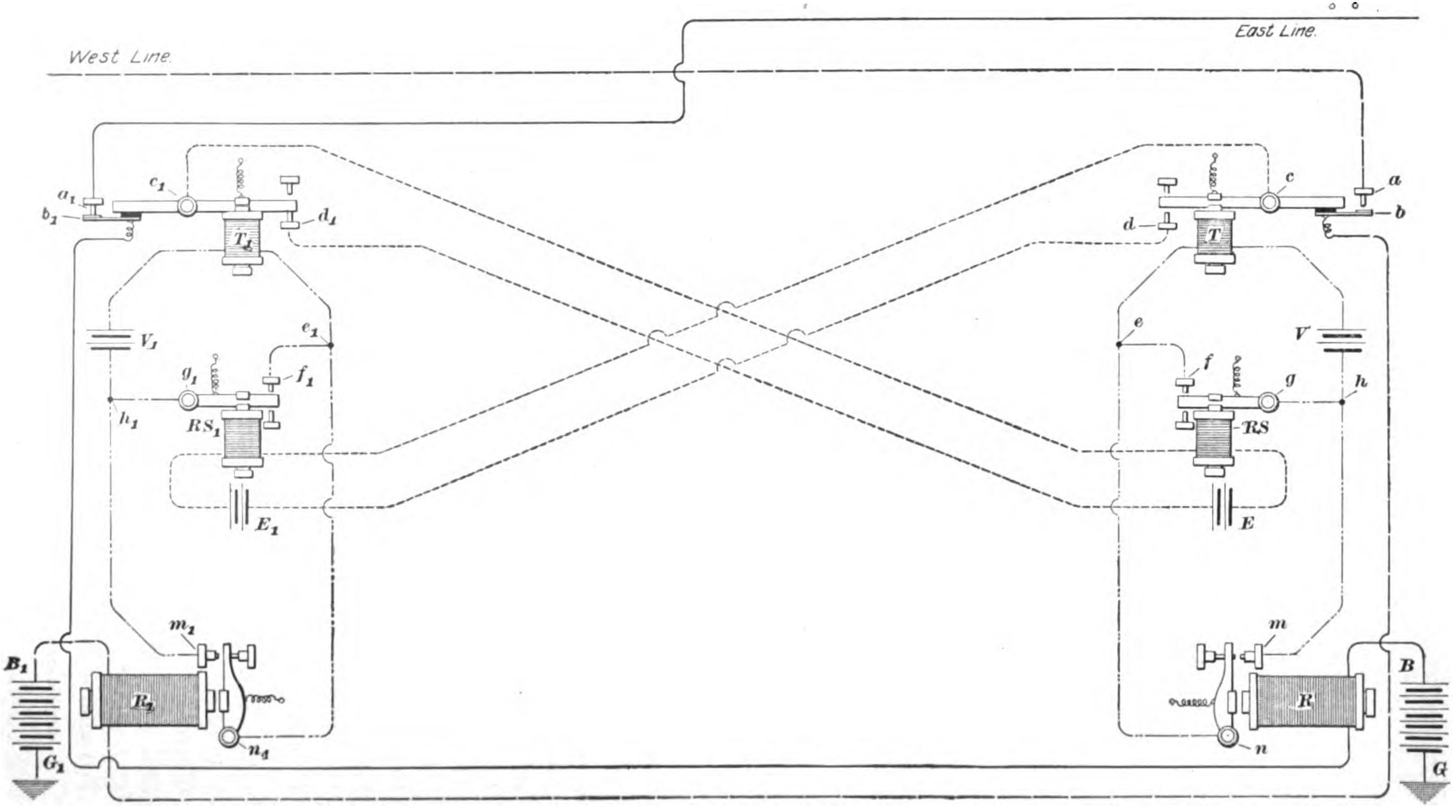
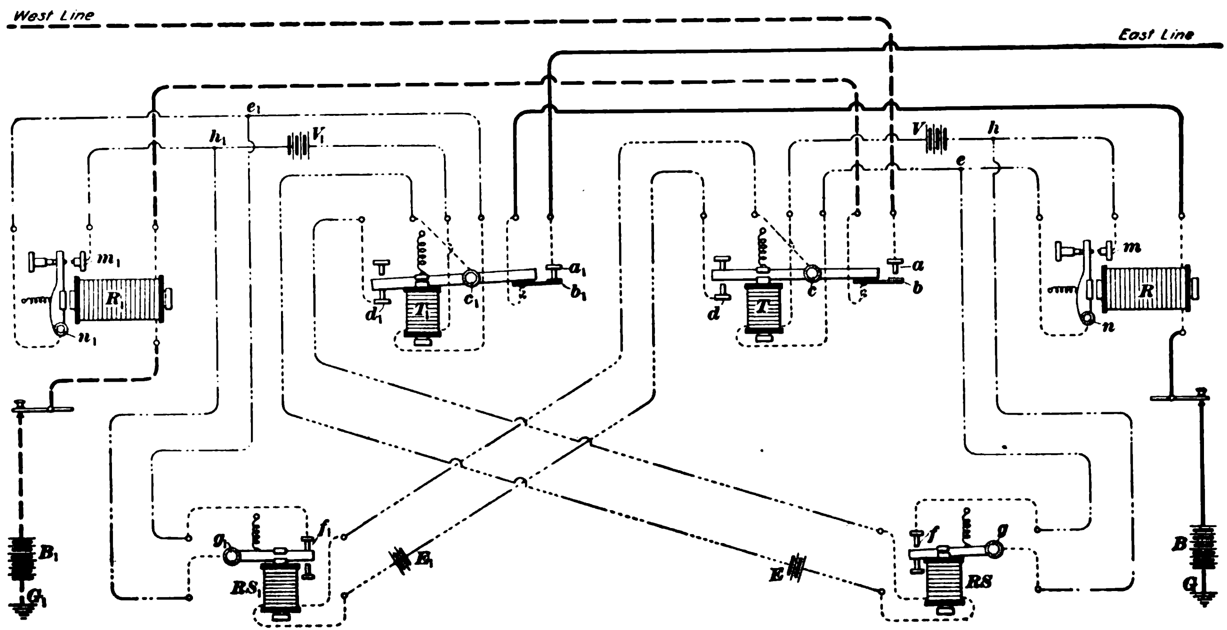

West Line
East Line
a_1
b_1
c_1
T_1
d_1
V_1
e_1
g_1
f_1
h_1
RS_1
E_1
m_1
B_1
R_1
n_1
G_1
a
b
c
d
T
e
V
f
g
h
RS
E
m
B
R
n
G

Fig. 1

affected by the opening or closing of the eastern key and remains closed as long as the western key is closed. The opening of the local circuit containing the transmitter T will cause this transmitter to release its armature and to open the extra local circuit at d and to open an instant later the western circuit at a. The opening at d of the extra local circuit containing the repeating sounder RS_1 and battery E_1 will cause the closing at f_1 of the shunt circuit h_1–g_1–f_1–e_1 around the armature m_1–n_1 of the relay R_1 slightly before, or at the same instant that the armature of the relay R_1 opens at m_1, on account of the relay R_1 being demagnetized, when the west line is opened at a. Thus the western circuit is opened at a and the transmitter T_1 is kept closed in spite of the fact that the relay R_1 releases its armature. Furthermore, the repeating sounder RS is kept closed at d_1, thereby preventing the closing at f of the local circuit containing the battery V and transmitter T, which, should it happen, would interfere with the signal.

When the eastern key is closed again, the relay R will close its local circuit at m, causing the transmitter T to close the western circuit at a, and a moment later, to close at d the extra local circuit containing the battery E_1 and repeating sounder RS_1. The closing of these two circuits first causes the relay R_1 to close its local circuit at m_1, and then the repeating sounder RS_1 to open at f_1, thus restoring all the circuits to their normal condition without opening the sending line (in this case the east line) at the repeating station. Therefore, the eastern circuit is not opened at any time at the repeater station while the eastern is repeating into the western circuit. Evidently, the operation described will be reversed when repeating from the western into the eastern circuit.

3. Local Circuits Operated by Batteries.—The regular desk connections of the Atkinson repeater as used by the Western Union Telegraph Company are shown in Fig. 2. Three gravity cells at V and V_1 for each transmitter and two at E and E_1 for each repeating sounder are sufficient, unless the leads to these batteries are long, in which case it may be



West Line
East Line
e_1
h_1
V_1
V
h
e
m_1
R_1
n_1
T_1
d_1
c_1
a_1
b_1
T
d
c
a
b
m
R
n
B_1
G_1
g_1
f_1
RS_1
E_1
E
f
g
RS
B
G

FIG. 2

well to use four cells for each transmitter. The relays R and R_1 should be adjusted until the signals are perfect; the relay springs should then be turned down a trifle to compensate for the time lost and the consequent shortening of the signals when passing through the repeater. This relay adjustment applies to about all repeaters. The spring of the repeating sounder should be adjusted until it is quite stiff so that the sounder will be comparatively quick to open and slow to close.

GHEGAN TELEGRAPH REPEATER

4. Local Circuits Operated by Batteries.—A test of many kinds of repeaters made in 1903, resulted, it is claimed, in the selection at that time by the Postal Telegraph-Cable Company of a repeater invented by Mr. J. J. Ghegan. A

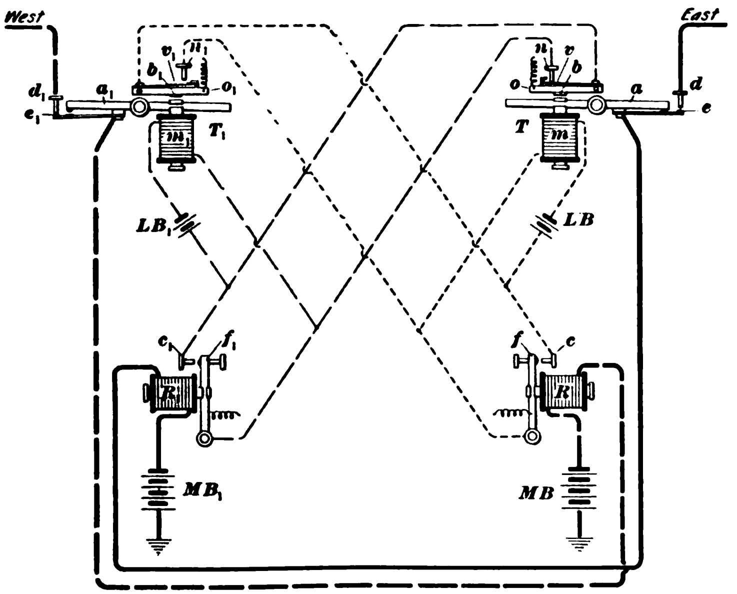


FIG. 3

diagram of connections of the **Ghegan repeater** is shown in Fig. 3. This repeater consists of two Ghegan telegraph transmitters T and T_1, and two ordinary telegraph relays R and R_1.

5. The Ghegan transmitter as actually constructed is shown in Fig. 4. In addition to the regular iron armature *a*, there is a second iron armature *b* attached to a separate short lever *o*. The lever *o* carries a spring contact *v* so arranged that it does not break contact with the back stop *n*, until its downward stroke is almost completed. This spring *v* makes contact with the backstop *n* immediately after the armature begins its upward movement, so that the circuit through contact *n* is always opened after the circuit through *d* is closed and it is closed before the circuit through *d* is opened. The second armature *b* is adjusted so that the regular armature *a*

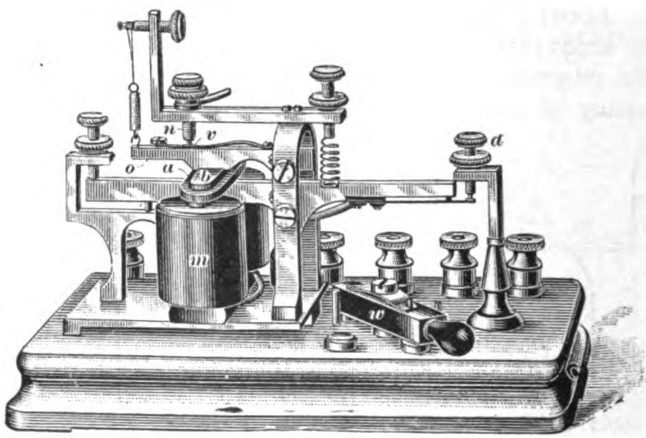


FIG. 4

must reach its lowest position, before the magnetism produced in it is sufficiently strong to draw the second armature *b* from its backstop. The object of this is to allow a sufficient margin of time between the closing of the main circuit by the downward movement of the first armature and the opening of the shunt circuit by the subsequent downward movement of the second armature, to permit the opposite relay, that is the relay in the same main circuit, to close its local contacts before the shunt circuit around them is opened by this transmitter. These repeaters, on account of the time elapsing between the closing of the main circuit and the opening of the shunt circuit, work well even on leaky lines where the relays act so

sluggishly as to render other types of automatic repeaters useless. The use of the switch w will be explained in connection with Figs. 5 and 6.

6. Operation of Ghegan Repeater.—The operation of the Ghegan repeater may be explained as follows: Normally all circuits in Fig. 3 are closed, except at contacts n and n_1, which are open, but when the key on the western main line at the distant station is opened, the instruments will assume the positions shown. The armature of relay R is first released and opens the local circuit containing the local battery LB and coils m of the transmitter T, which in turn opens the eastern line circuit at d, thus repeating the signal into the eastern line circuit. The armature of relay R_1 is also released, but it does not affect the local circuit containing the coils of the transmitter T_1, because before the eastern circuit was opened at d, the shunt around the local contacts of relay R_1 was closed between n and v, hence, the circuit containing the coils m_1 is not opened and the continuity of the sending circuit at the repeater is maintained.

When the western key is closed, the armature of relay R closes the local circuit of transmitter T, which causes the eastern circuit to be closed between contacts d and e, thus repeating the signal. The relay R_1 also attracts its armature and by closing the circuit of the transmitter magnet m_1 between contacts c_1, and f_1 prevents the opening of this circuit containing local battery LB_1 and transmitter magnet m_1 when the transmitter T, a moment later, separates contacts n and v. Thus the western transmitter T_1 is held closed while the western operator is sending.

Should the eastern operator break while the western operator is sending, the armature of relay R_1 will remain against its backstop f_1, thus breaking the local circuit containing the transmitter magnet m_1 on the first downward stroke of the second armature b of the transmitter T and so break the western circuit between contacts d_1 and e_1. To repeat from the eastern into the western circuit, the foregoing operations are reversed.

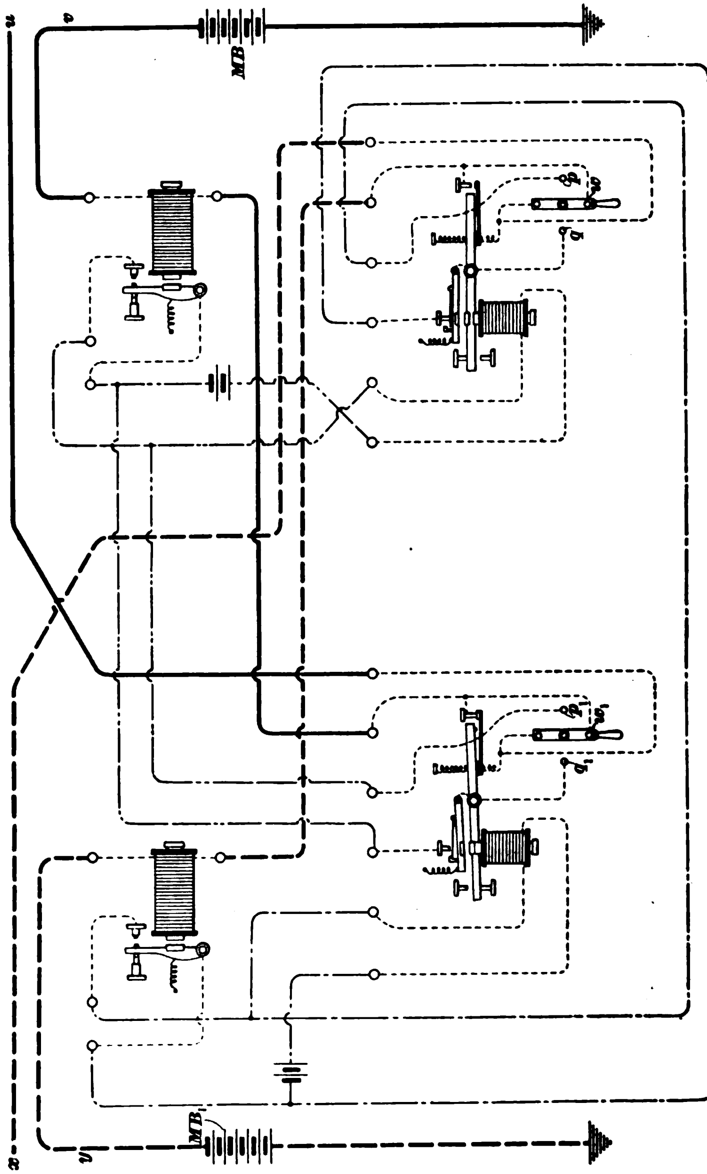


Fig. 5

7. Owing to the double air gap between the magnet cores and the extra armature, the latter is operated merely by induction or magnetic leakage, and therefore the tractive pull on the extra armature is only a small percentage of that on the main armature. The tractive pull is also very susceptible to small changes in the number of lines of force in the magnet and its main armature. This has been the chief difficulty with the repeater wherever installed. The slightest change in the voltage of the dynamo or storage battery was sufficient to cause some trouble with all repeaters. When first sent out the spring on the extra armature was too heavy and required careful adjustment, but this was remedied by attaching a much more flexible spring which has considerably improved the original working of the transmitters. The claim of economy under gravity or other battery operation is very questionable as it is found necessary to provide a correspondingly stronger current through the magnet when it is called upon to operate two armatures.

8. Practical Arrangement of Ghegan Repeaters. In Fig. 5 is shown the practical arrangement of the Ghegan repeater when the batteries are used for its operation. Each transmitter is provided with a switch. In the position of the two switches w and w_1 shown, the eastern and western lines may be used as two independent telegraph circuits. In their other position, one switch w connects contacts p and q and the other switch w_1 connects contacts p_1 and q_1 and the apparatus acts as a repeater in the manner described. Usually the wires x, y, u, and v are run to the switchboard and there connected to the line wires and through the main batteries MB and MB_1 or dynamos to ground.

9. Local Circuits Operated by Dynamos.—In Fig. 6 is shown the wiring of the Ghegan repeater as used by the Postal Telegraph-Cable Company when all local circuits are supplied with current from a 40-volt dynamo. All binding posts or terminals similarly lettered are connected together. Where the local circuits are supplied by batteries, one terminal of one battery is connected to binding post a on the relay R_1

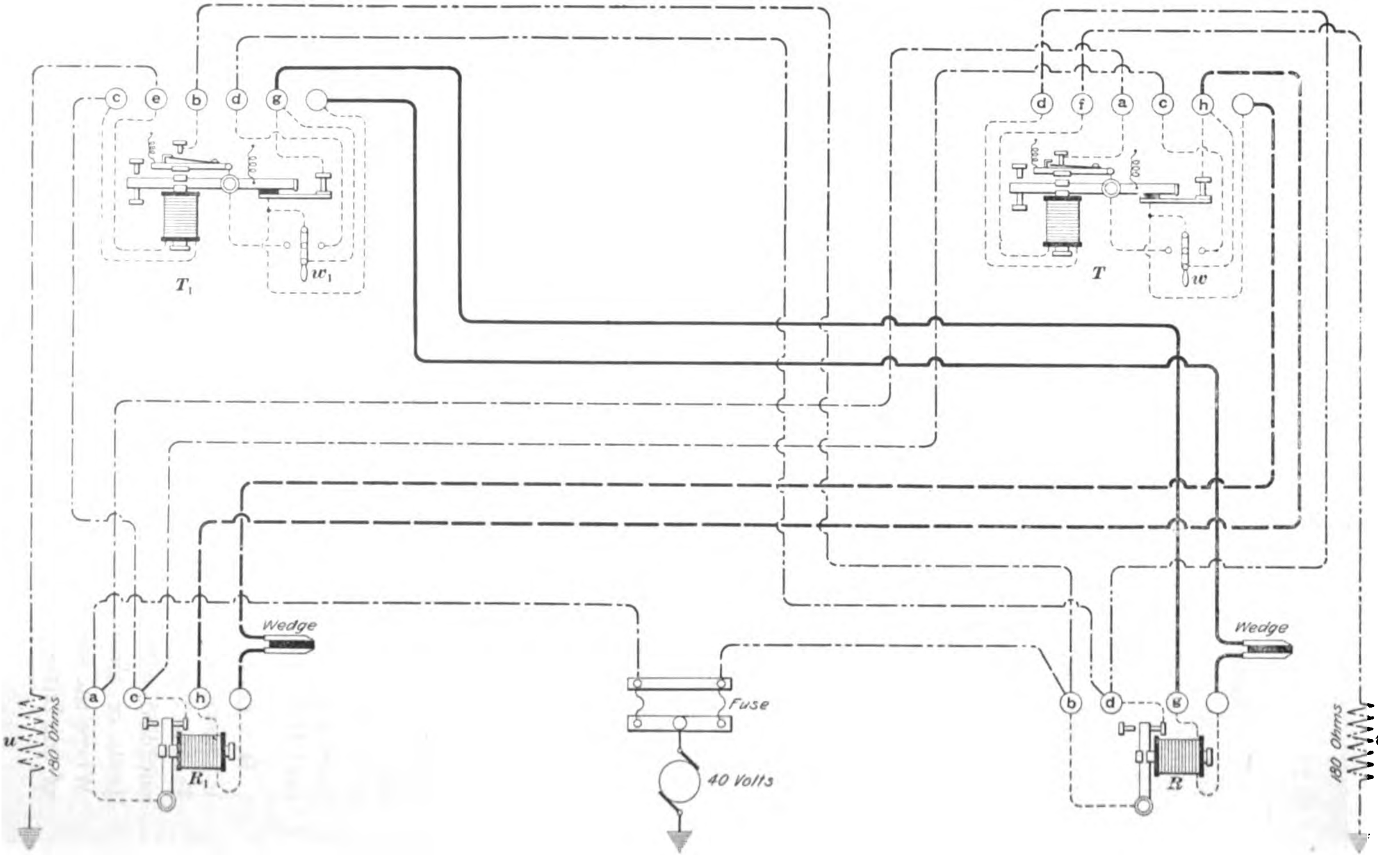


FIG. 6

and the other terminal of the same battery to binding post *e* on the transmitter T_1. Another battery has its terminals connected to binding posts *b* and *f* and the 180-ohm coils *u* and *v* will be disconnected from posts *e* and *f*.

LEWIS AND McINTOSH REPEATER

10. Direct-Point Repeater.—The **Lewis and McIntosh repeater,** shown in Fig. 7, may be called a *direct-point repeater* because the relay in one line repeats directly into the other line, no transmitters or repeating sounders being used. In fact, only two relays are required, although two local sounders are provided to enable the attending operator to read the

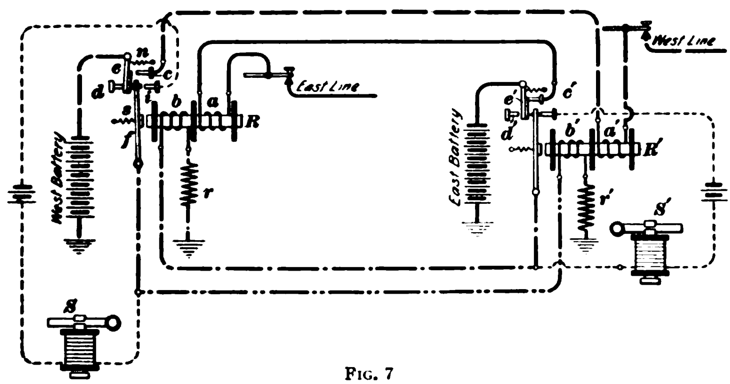


Fig. 7

passing signals. The Lewis and McIntosh repeater resembles the Toye repeater because the resistance *r*, which is equal to the resistance of the east line, is substituted for the east line in the open position of the relay *R'*. Similarly the resistance *r'* is substituted for the west line. As the spring *s* is stronger than the spring *n*, both contact levers rest against the stop *d* as shown for relay *R*, when no current flows through either coil on the relay. When the circuit is closed, the lever *f* rests against stop *i*, but is not touched by lever *e*, which then rests against stop *c*, as shown at relay *R'*. The repeater was used continuously in a line circuit for nearly a year and it was claimed that it proved reliable in all kinds of weather.

11. Operation of Lewis and McIntosh Repeater. With all currents in their normal, closed, position, there will be no circuit flowing in the artificial line coils b and b'. When, therefore, the distant eastern key is opened, the coil a will be deprived of current and the relay R will release its armature, thereby opening the local sounder circuit. Almost immediately the west line is opened at c and replaced by the coil b', and resistance r' which are now connected through contacts f and e to the west battery; thus the relay R' is kept magnetized and none of the circuits controlled by it are affected.

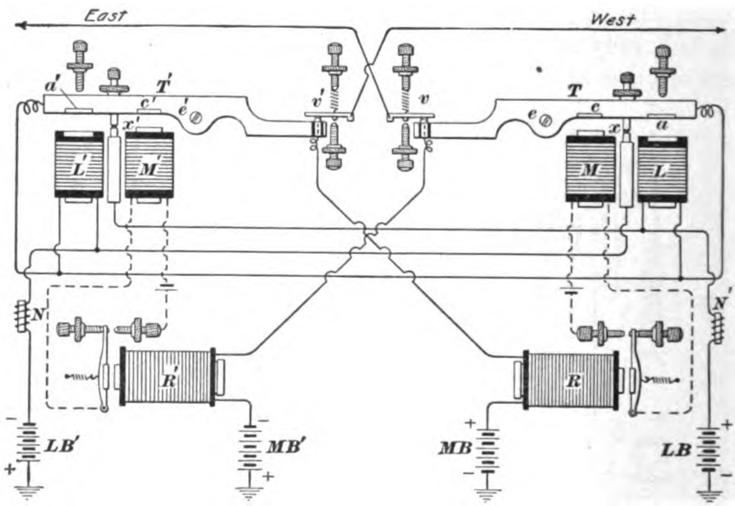


FIG. 8

When the eastern key is closed, current flows from the east battery through e'–c'–a to the east line, the relay R attracts its armature, and the west line is connected through contacts c and e with the west battery. The resistance r' and coil b' are then disconnected between contacts f and e from the west battery, and the local sounder circuit is closed at i. Thus all circuits are restored to their normal condition.

Should the operator in the western office break his circuit while the eastern key is open, no effect is produced because the west line is already open at c. But when the eastern key is closed, the relay R will attract its armature, thereby depriving

the coil b' of current, and as no current is flowing in coil a' the relay R' releases its armature, opens the eastern line, closes the eastern battery through coil b and resistance r, thereby causing the relay R to hold its armature. This is the same condition that occurs when the western operator opens his key while sending regularly.

STANDARD REPEATER

12. Fig. 8 shows the theoretical connections of a repeater used by the American Telephone and Telegraph Company and at one time called their **standard repeater.** Ordinary 150-ohm or 250-ohm relays R and R' may be used as desired. The telegraph transmitters T and T' are especially made, having additional 20-ohm electromagnets L and L' under the extreme ends of the transmitter bars, to which are fastened the soft-iron armatures a, a', c, and c'. The bars are pivoted at e and e'. The magnets L and L' are fastened to the base by adjustable screws, which are used to draw them away from or advance them closer to their armatures, as desired. Normally, all circuits are closed and the holding magnets L and L' have their coils short-circuited through the contacts x and x'. Current flows through the limiting resistances N and N' continuously, but only passes through the holding magnets when either the west or east line is open, which allows a relay R or R' to open and deprive a magnet M, or M', respectively, of current. The dotted lines show the local circuits for operating the transmitters, magnets, M and M'.

13. Operation of Standard Repeater.—When a telegraph operator at the distant western station opens his key and hence opens the west line, the relay R releases its armature, thus opening the local circuit through the magnet M of the transmitter T. The transmitter bar in its upward movement first opens the contact at x, which removes the shunt from around the holding magnet L', and allows it to receive current through LB–N'–x'–L'–N–LB'-ground and thus hold the bar of transmitter T' in the closed position even after the current, a moment later, is cut off from the coils M'. Passing

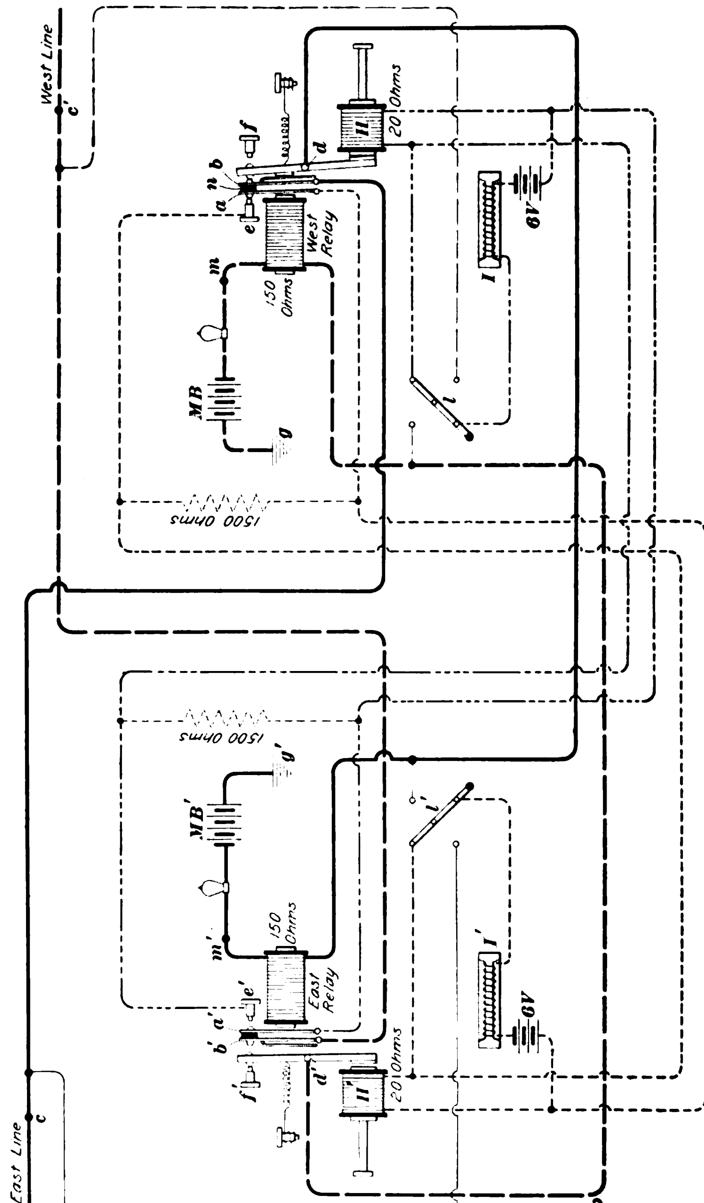

West Line
c'
f
a
n
b
e
d
West Relay
150 Ohms
m
20 Ohms
MB
g
I
6V
l
1500 Ohms
1500 Ohms
MB'
g'
l'
I'
6V
m'
150 Ohms
East Relay
e'
a'
b'
f'
d'
20 Ohms
East Line
c
p

Fig. 9

upwards the bar of transmitter T next breaks the contact at v, thus opening the east line, and allowing the relay R' to open. Hence, opening the west line at the western station opens the east line at the repeater, but the west line is not opened at the repeater. Closing the western key will close the relay R, then the magnet M, also the eastern circuit at v and the shunt around L' at x, thus restoring all circuits to their normal condition.

Should the east, desiring to stop and communicate with the sending operator at the western station while the eastern line is open at v, *break*, that is open his key at the eastern station, the relay R' will remain open and just as soon as the bar of the transmitter T completes the next downward movement caused by the closing of the western key, the shunt at x around the magnet L' will be closed, thus allowing the bar of T' to fly up and open the west line at v'. The opening of the shunt at x' around the magnet L causes the magnet L to hold down the lever T'; thus the eastern line is closed at v and the western line is open at v'. Hence the eastern operator can now send to the western operator.

14. Adjustment of Standard Repeater.—In practice, the holding magnets L and L' should be just sufficiently near to their armatures to pull down the bar when the shunt is removed. If brought too close, the break is not sufficiently rapid. Getting one a little too far away will introduce a "rattle" in the repeater; or it may leave the line standing open when one side breaks.

The main-line contacts at v and v' should be as close as possible without arcing across. The springs on top of these little contact bars should be just strong enough to make good contact, but not too stiff.

To adjust the holding magnets, throw the two switches, usually provided on the repeater table, but not shown in Fig. 8, to the left and open the two telegraph keys also provided but not shown here. Taking firm hold of one transmitter bar, work it up and down slowly; the opposite transmitter bar should follow these motions. If it does not, adjust the holding magnet under it until it does so. Now change and

operate the opposite bar by hand and adjust the holding magnet on the one first worked by hand. If this is done, the adjustment is sure to be correct. Only experienced men should attempt to adjust the magnet while the repeater is working.

ATHEARN REPEATER

15. In Fig. 9 is shown a repeater devised by Mr. W. E. Athearn for the American Telephone and Telegraph Company, which, it is claimed, is simpler, quicker, and more direct in action than the Standard repeater. It is known as the **Athearn repeater.** It contains two ordinary 150-ohm relay magnets which are provided with the usual front stops *e* and *e'* and back stops *f* and *f'*. In addition, each relay has two slender springs *a* and *b* separated by a hard rubber washer *n*. These springs are fastened to the base and fit in between the two coils of the relay, although for the sake of clearness they are shown in front of the coils. To illustrate the connections more clearly, these springs are frequently shown as projecting upwards. The armature lever, which is pivoted at *d*, is very light and extends downwards as well as upwards. The iron armature for the 150-ohm relay magnets is fastened to the lever above the center and the iron armature for the 20-ohm holding magnet *H* is fastened below the center of the lever. The holding magnet *H* is fitted into a deep groove in the bottom of the base, which is a rather thick wooden one mounted on an iron frame. Both relays, with their respective holding magnets, are mounted back to back on one long base. A 1,500-ohm non-inductive resistance is connected, as shown, across each pair of contacts *a* and *e* to reduce the sparking when they separate.

16. A novel feature of the Athearn repeater is the limiting resistances *I* and *I'*, which, instead of being non-inductively wound, are wound on iron cores with heavy end lugs. It is stated that because of this inductance the holding magnets *H* and *H'* act more quickly because, when the short circuit is removed from around one of these magnets, the coil *I* or *I'* gives

a practically instantaneous kick of much more than 6 volts, which helps to overcome the high impedance of the holding magnet for a rapidly increasing current and, therefore, to more rapidly build up its magnetism. This repeater is claimed to be very rapid on account of the lightness of the moving parts.

17. Operation of Athearn Repeater.—In the normal condition, all circuits are closed. If the western operator desires to send and opens his key, there is no current in the circuit west line b'–d'–p–west relay–m–resistance lamp–main-line battery MB to ground g, and hence the west relay releases its armature. As the armature moves backwards, it first opens the circuit between contacts e and a, thereby opening a short circuit around the holding magnet H', which then receives current from the 6-volt battery that is in the circuit containing the switch l' and resistance I'. This prevents the holding magnet from releasing the lever d' of the east relay when, a moment later, the further backward movement of the lever d of the west relay opens the east line passing through the east relay between the spring b and the lever d. Thus, the eastern line is opened at b, but the west line does not open at the repeater at b' or elsewhere. When the western operator closes his key, the west relay attracts its armature, closes the east line between the spring b and the lever d, and then closes the shunt between contacts e and a around the holding magnet H'. All circuits are now restored to their normal condition.

Should the eastern operator, desiring to break, open his key while the eastern line is also open between the spring b and the lever d, the first complete forward motion of lever d, due to the closing of the western key and then the west relay, closes the east line between the spring b and the lever d and also closes the short circuit around the holding magnet H' which, therefore, no longer holds the lever d'. Consequently the lever d' is pulled backwards by its spring and it opens (between contacts a' and e') the short circuit around the magnet H which then holds its lever should the circuit containing the west relay be opened by the western operator. The contacts b' and f' are not brought together. Hence the east line is held closed

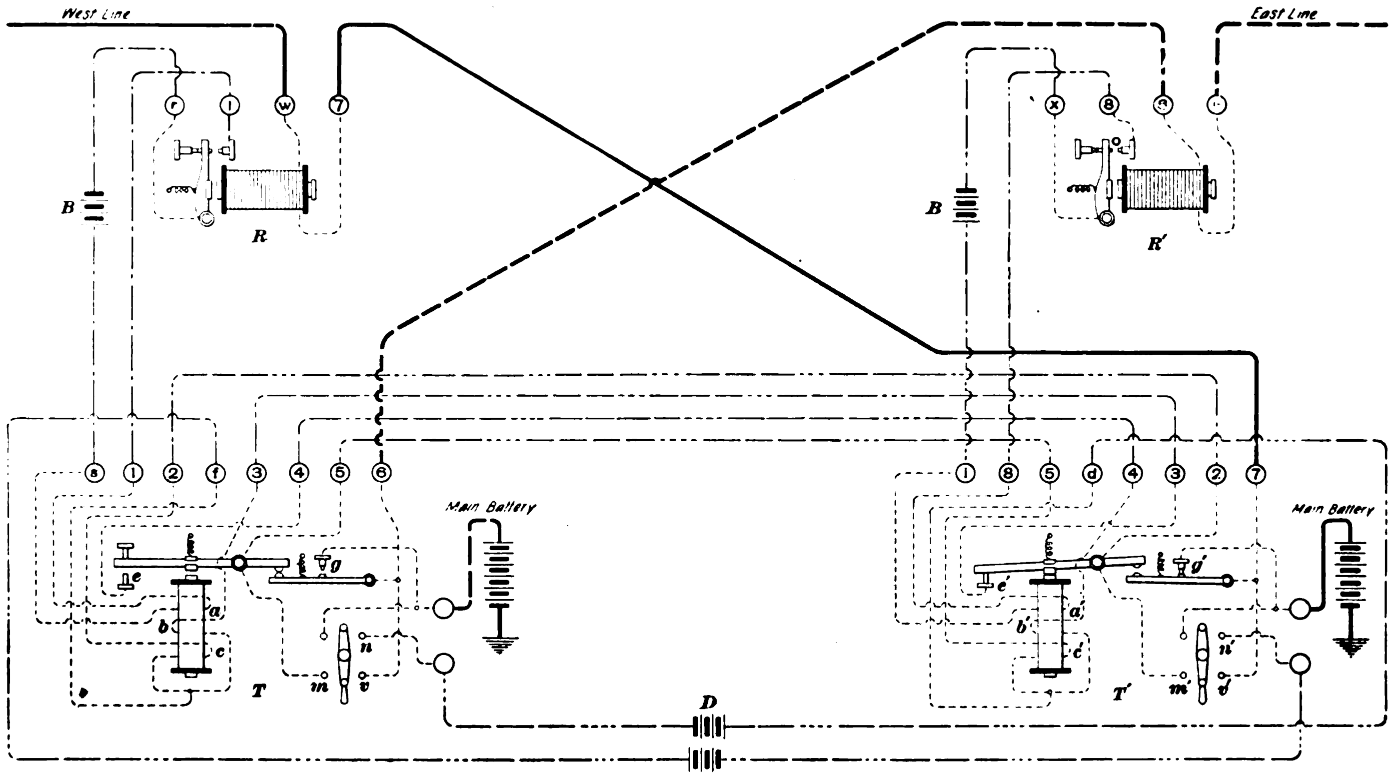


Fig. 10

at the repeater between the contacts b and d in spite of the eastern key being open. The eastern operator can then send to the western operator.

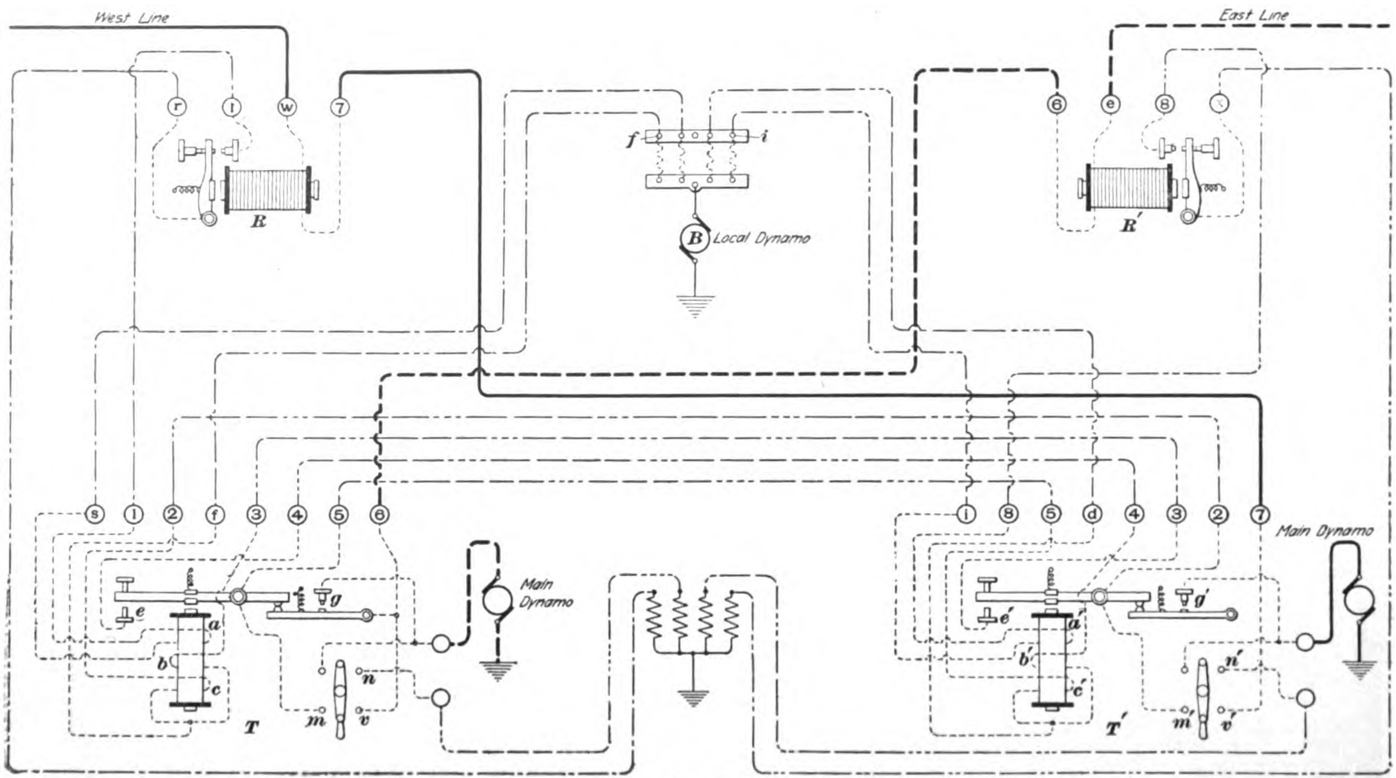
By turning the switches l and l' away from each other, the circuits containing the holding magnets and their batteries are opened and each line is connected directly through its own relay and main-line battery to ground; thus the lines may be used independently of each other, that is, without the repeater. A 6-volt battery is used to operate the 20-ohm holding magnet.

18. Morse Board Connections.—Telegraph apparatus used by the American Telephone and Telegraph Company is usually connected to lines and batteries through a switchboard, called the **Morse board.** The wires coming from this repeater to points c, c', m, and m' terminate in plugs upon the shelf of the Morse board, while the line and battery wires terminate in spring jacks upon the upright face of the board. Then by inserting the plugs in the proper jacks the repeater can be connected to any desired lines and batteries.

F. W. JONES REPEATER

19. Battery and Dynamo Local Circuits.—An automatic telegraph repeater patented by Mr. F. W. Jones is shown in Figs. 10 and 11. The local circuits in Fig. 10 are arranged for batteries; the local circuits in Fig. 11 are arranged for dynamos. The improvements claimed for this repeater are: (1) An increase in the certainty of operation. (2) Reduction in the cost of instruments required. (3) Any adjustment made upon the main-line relay will not affect the holding power of the opposite transmitter. (4) Extra holding magnets are not required. (5) In case of damage to the relay, a workable relay can be more readily substituted than one having special magnets or attachments. However, this repeater requires a transmitter with a special three-coil winding, while there are successful repeaters requiring only standard relays, transmitters, and repeating sounders.

To use the apparatus as an automatic repeater, the switches on the bases of the transmitters should be turned to the left,



West Line
East Line
R
R′
f
i
B
Local Dynamo
Main Dynamo
Main Dynamo
T
T′

FIG. 11

so as to connect together points m and n, for instance, on both transmitters. To make two independent lines with a relay in each circuit these switches should be turned to the right.

20. Operation of the F. W. Jones Repeater.—With the switches turned to the left and all circuits closed, the current flowing in coil b of the transmitter T is neutralized by that in coil c, therefore the current in coil a is sufficient to hold the transmitter closed. Coils a and c convey the current in the same direction around the core while the current in coil b flows around the core in the opposite direction. When the operator at the western end of the circuit opens his key, the west line is opened. This allows relay R to release its armature and opens the circuit through coil a. As coils b and c neutralize each other, the transmitter T releases its armature, thereby opening first at e, the circuit through coil b' and then at g, the east line containing the relay R', which in turns opens the circuit through coil a'. As current continues to flow through coil c' the transmitter T' is held closed and hence the sending line, in this case the west line, is not opened at g'.

21. When the operator at the west office closes his key, the relay R attracts its armature, current flows through coil a, thereby closing the transmitter T, which causes current to flow first through the relay R' and the east line, then through coils b' and c', which restores all circuits to normal condition. Even if contact e should be closed long enough before contact o to send current through coil b' before it flowed through coil a', no serious result would follow, because even should the transmitter T' thereby start to release its armature, the opening of the circuit through coil b at e' would not cause the transmitter T to release its armature because current is flowing through both coils a and c, which assist each other in magnetizing the core. The apparatus should be adjusted so that the circuit closes at o before it closes at e.

22. Should the eastern operator break while the western operator has his key open no effective change in the condition of the circuits takes place, because this merely produces a

second opening in the east line which is already open at *g*. But when the western operator closes his key, the relay *R* closes, then the transmitter *T* closes, thereby sending current through coil *b'* which neutralizes that in coil *c'*. Moreover, relay *R'* is open so that coil *a'* cannot receive current, hence the transmitter *T'* opens, the western line is opened at *g'* and coil *b* is deprived of current. This is practically the same action that takes place when the eastern operator opens his key while sending messages to the western operator.

PERMANENTLY ADJUSTED REPEATER

23. While it is hard to convince an operator that it is possible to construct a single-line repeater that requires no attention after it has been properly adjusted, the inventor of the **permanently adjusted repeater,** Mr. Fred Catlin, maintains that this instrument is practically a permanently adjusted device. It made a record to that effect from 5:30 P. M. till

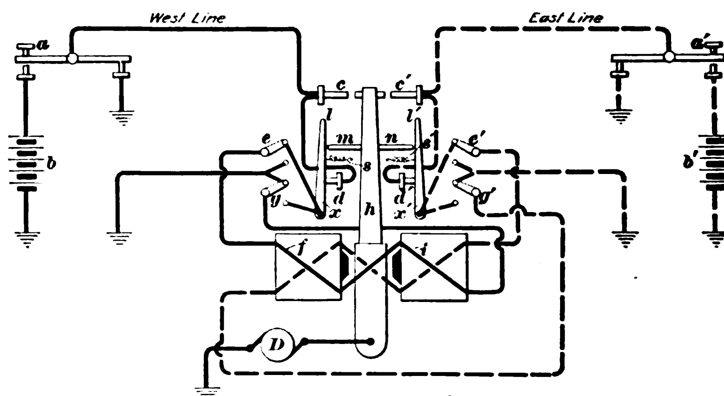


FIG. 12

3 A. M. one severe night when all other types of repeaters demanded almost constant attention. The information concerning this repeater is abstracted from an article in the Telegraph Age by Mr. W. H. Jones.

Fig. 12 shows that the repeater is what might be called an **open-circuit repeater,** because, when the repeater is not in

use, there is no current flowing in either line wire. Each line is grounded through the transmitter points when the key in that line is open, which is its normal position when not in use. The key requires a grounded backstop. The repeating relay is an ordinary polarized relay, such as is used extensively in connection with polar-duplex systems. Here it is sufficient to say that a current in one direction through one winding tends to move the armature to one side and a current in the other direction through the same winding, or any combination of current-direction and winding that reverses the magnetism of the relay tends to move the armature to the other side of its middle position. This relay has the usual two windings on each coil, one winding on each coil being in series with one of the two line wires. The retractile springs s and s' tend to hold the levers l and l' against the stops d and d'. When no current flows through either winding of the relay, the main lever h will not be drawn to either side with sufficient force to open the contacts between levers l and l' and their stops.

24. Operation of Permanently Adjusted Repeater. When the key a at the western station is closed current flows from the battery b through west line-stop d–lever x–switch arm e–windings f and i on the coils–switch arm g to ground. This causes the large lever h to move against stop c', thereby permitting current from the dynamo D to flow through the eastern line to ground at that station. In order that no current shall flow through the opposing windings of the relay the cross-arm $m\,n$ is so arranged that it moves lever l' away from d' just before h touches c'. Opening the key a deprives the windings in series with the switch-arm e and the west line of current and opens the circuit again at c'. When the eastern station breaks by opening key a' or starts sending, the action is simply reversed.

25. By means of the switches shown, the direction of current from terminal-station batteries may be reversed through the windings of the relay whenever the polarity of the distant battery demands it. The efficiency of this repeater is doubtless

due to the fact that the relay is controlled by reversing the direction of the current, instead of changing the strength of the current. Besides it is not easily thrown out of order by changes in the strength of the current, which occur in a line during a temporary downpour of rain. The absence of local-battery circuits and trunnions also eliminates a number of adjustable points present in other repeaters. The permanently adjusted repeater is not available for circuits requiring intermediate stations, but a transmitter located at a terminal office may have its local circuit extended to broker or district offices where a key may be used to control the transmitter.

HORTON REPEATER

26. The **Horton repeater,** which was introduced in 1896, is said to have been used by the Lehigh Valley Railroad, Philadelphia and Reading Railroad, the National Transit Company, on some of the lines of the Long Distance Telephone

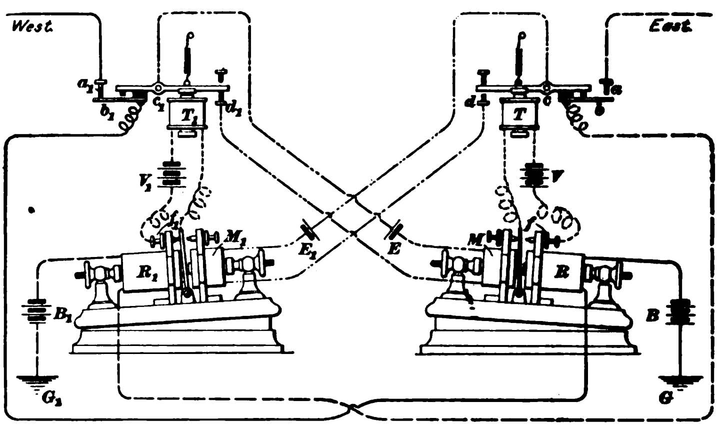


Fig. 13

Company, North American Telegraph Company, and the Pennsylvania Railroad lines west of Pittsburg. Its distinguishing feature is the method adopted for preserving the continuity of the sending circuit while repeating into the opposite line. This is accomplished by using the force of gravity, dispensing

with extra armatures or springs, the holding force being obtained by the withdrawal instead of the application of a local current.

27. In Fig. 13, T and T_1 are ordinary repeating transmitters and R and R_1 are main-line relays. The latter have inclined bases and local retracting magnets M and M_1 that are placed directly behind the relay armatures. The retracting magnet acts, when energized, on the armature as a retractile force (in place of the usual spring) to draw it backwards and away from its local contact when the main-line current through the front or relay coils is interrupted. On account of the inclined base, the armature will retain its forward position by gravity, and so keep the local circuit through the transmitter closed whenever there is no current in the retracting magnets, regardless of the presence or absence of a current through the relay coils in front. When both the relay and the retracting magnets are energized, the pull of the relay on the armature, aided by gravity, is sufficient to keep the armature of the relay R against the front contact f, and thus keep the transmitter T closed. Consequently, the transmitter T can only be opened when there is current in the retracting magnet M and none in the relay magnet R.

The retracting magnet may be moved toward or away from the armature as desired, in order to increase or decrease its attractive force on the armature, in the same manner as an ordinary relay is adjusted. This is the only part of the repeater requiring adjustment after it has once been properly set up, and for this reason it is said to give better results than some other repeaters in the hands of ordinary operators.

28. Operation of Horton Repeater.—In their normal condition, all circuits are closed. Opening the western key interrupts the current through the relay R, the armature of which is thereby drawn away from its local contact f by the attraction of the retracting magnet M, which remains closed. This permits the transmitter T to open first at d the local circuit of the retracting magnet M_1, and then at a the eastern circuit. The opening of the local circuit at d demagnetizes the retracting magnet M_1. This prevents any movement of

the armature of the relay R_1, which continues to be held against its front contact stop f_1 by its own weight, when, an instant later, the east main-line circuit passing through the relay R_1 is opened at a. Thus the local circuit containing the magnet of the transmitter T_1 is kept closed, thereby preserving at a_1 the continuity of the western main-line circuit. A closed path is thus preserved from the western office through a_1–b_1–R–B–G back through the ground to the western office, thereby enabling the western office to again close the relay R. When the operator at the western office does this by closing his key, the relay R attracts its armature, closing at f the circuit containing the transmitter T, which, in turn, first closes the east line at a, causing the relay R_1 to hold on to its armature when, a moment later, the local circuit containing the retracting magnet M_1 is closed at d. Now all circuits are again closed, which is their normal condition. Therefore, the western circuit is not opened at any time at the repeater while the western is repeating into the eastern circuit. The operation described will be reversed when repeating from the eastern into the western circuit.

29. Advantages of Horton Repeater.—It is claimed that the Horton repeater is very efficient and sensitive. As it permits the closest possible adjustment of both relay and transmitter armatures, the play of these may be so shortened that their motion is scarcely perceptible, which, together with the instantaneous application of the holding force, increases the capacity of the repeater for rapid work. Any marked decrease in the strength of the extra local current can be quickly compensated for by bringing the retracting magnet closer to the armature. It is further claimed that one cell is sufficient for each extra local battery E and E_1, as against six in each extra local circuit of the Milliken repeater, and that the transmitter can be operated with less battery power on account of the close adjustment possible, thus saving about ten cells of local battery where this repeater is used in place of the Milliken. Like the Milliken and other repeaters, the Horton repeater may be divided into half sets for use in connection with the duplex or quadruplex systems.

DRY-CELL REPEATER

30. The dry cell supplies a certain quantity of electricity, requires no attention for maintenance, gives out its energy as demanded, and is cheap enough to be thrown away when no longer useful. It is especially applicable where a small amount of electrical energy is required intermittently over a long period, and where it would be more expensive or inconvenient to secure this energy from dynamos, or electric-lighting circuits or storage batteries. Other primary cells are much more troublesome and no cheaper. The field for the application of dry cells is widening.

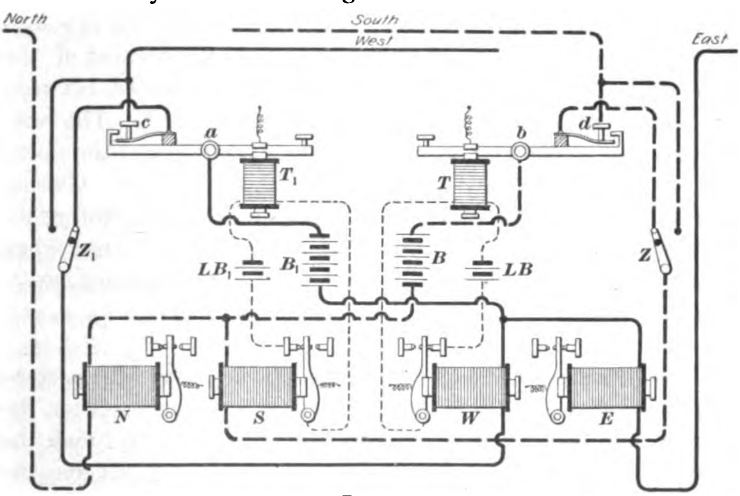


FIG. 14

Mr. Fry has devised the arrangement shown in Fig. 14, in which dry cells are used to operate an automatic telegraph repeater. The current required from the dry cells is reduced to a minimum and the electrical energy is used to the best advantage. Only the set of dry cells on the receiving side is in use and the current flows only during the space or open period of the sending line. As the sending and receiving functions are alternated, the two sets of cells are alternately brought into use, the duration of closed circuit intervals being reduced to a minimum.

31. Operation of Dry-Cell Repeater.—The normal condition of the circuits is shown in Fig. 14. The east and west lines with relays E and W form a continuous circuit; similarly the north and south lines with relays N and S form another continuous circuit. Each of these circuits has a battery at one or both terminal stations. The transmitters T and T_1 are held closed by the local batteries LB and LB_1, for which dry cells are not suitable, as they are in a circuit closed most of the time.

When the eastern station, in the act of transmitting a message, opens the key, relays E and W open, thereby opening the circuit of the transmitter T, which in turns opens the south line at d, and also closes the circuit containing the dry battery B and the relay S, thereby preventing the opening of the transmitter T_1. The north line has its circuit opened between the spring tongue and stop d of the transmitter T. The west line is open at the key at the eastern station. Thus the opening of the eastern key opens the other three lines. Closing the eastern key will close all the line circuits and restore all circuits to normal condition. A similar action occurs when the north line is sending, thereby repeating into the east, west, and south lines.

32. If the western operator opens his key while the eastern key is open, all the line circuits remain open, even after the eastern key is closed; thus the western operator can break the sending eastern operator and the other operators receive the same notice for their circuits also remain open until both east and west keys are closed. If the southern operator by opening his key opens the south-north line containing the relay S, which in turn allows the transmitter T_1 to open the east-west line at c, the sending eastern operator is broken for he cannot then close the east-west line by closing his own key. Similarly opening the northern lines breaks the eastern sending operator and holds all lines open until both northern and eastern keys are closed.

The operation of repeating from any other line to the three remaining lines is similar to that just explained. Thus any

terminal station can send messages to the three other terminal stations and any receiving operator can break the sending operator. By turning the switch Z_1 to the left and switch Z to the right, the repeater is thrown out. The east and west lines are then connected together and the north and south lines are connected together. Relays E and N are used to operate reading sounders for the convenience of the attending operator.

Various other repeaters, such as half repeaters, defective-loop repeaters, double-loop repeaters, and those used in connection with multiplex sets are treated elsewhere. Before studying such repeaters, double-current, duplex, and quadruplex systems should be understood.

DOUBLE-CURRENT SYSTEM

INTRODUCTION

33. The Morse open-circuit and closed-circuit systems are sometimes called **single-current systems,** because the current in the line and relays, while a message is being transmitted, flows only in one direction. A dot or a dash is caused by a current flowing through the relay, while a space is caused by the absence of a current. It makes no difference in which direction the current flows through the relay, because a current in either direction will cause the relay to attract its armature.

In the **double-current system,** reverse currents, or currents in both directions through the line and relays, are employed. A current in one direction through the relays produces dots and dashes, and a current in the opposite direction is necessary in order to produce a space. The double-current system is used on all submarine cables, on polar, quadruplex, Wheatstone automatic, and printing telegraph systems, and more or less on simplex land lines throughout Europe. A **simplex circuit** is one over which only one message is sent at one time.

POLARIZED RELAYS

ACTION OF POLARIZED RELAYS

34. For double-current transmission, *polarized relays* are necessary in place of the ordinary relays employed on single-current systems. A **polarized relay** is one that requires the direction of the current flowing through it to be reversed in order to move the armature from one stop to the other. A current in one direction will keep the local-sounder circuit closed at the front stop of the relay, and a current in the reverse direction is necessary before the local-sounder circuit can be opened at this point. The mere absence of a current will leave the armature of the relay against whichever stop the last current may have moved it. Dots and dashes are made by currents flowing in one definite direction and spaces by currents flowing in the opposite direction. A battery reversing key must be employed in place of the ordinary make-and-break key.

35. In telegraphing by means of the Morse single-current system, the opening of the key leaves the line charged. This charge flows to earth through the path of least resistance, requiring on a long line, and especially on submarine cables, an appreciable time for the total charge to reach the earth through the ground connection at the distant end. If the key is so constructed that instead of simply opening the circuit it connects the opposite pole of the same, or a similar battery, to the line, the charge of opposite polarity rushing from the battery into the line will neutralize more or less of the original charge remaining on the line, thus reducing the latter to a neutral, or unchanged, state much more quickly than if all the original charge had to flow to earth before the line would be clear. Thus the line is ready for a new signal in a shorter time than under the single-current system and, consequently, more rapid transmitting is possible.

By using polarized relays and double currents, **190** words a minute can be transmitted by the Wheatstone automatic

system between New York and Chicago, whereas, on the ordinary Morse single-current system, 80 words is about the limit on a line only 350 miles long. However, the greatest advantage of the double-current over the single-current system is probably due to the higher efficiency of the polarized relay over the ordinary relay, especially during wet weather when there is a large amount of leakage from the line.

THEORY OF THE POLARIZED RELAY

36. Polarity of Soft-Iron Cores.—If a coil of insulated wire is wound around a soft-iron core and is connected to a battery so that the current circulates around the iron core in the direction shown by the arrows in Fig. 15 (*a*), the iron will

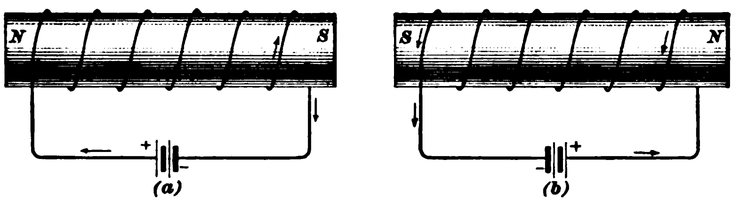


FIG. 15

be magnetized, having a north pole N at the left-hand end and a south pole S at the right-hand end. If the battery is reversed, so that the current flows in the opposite direction, as shown by the arrows in (*b*), the magnetism will be reversed, having now a south pole S at the left-hand end, and a north pole N at the right-hand end.

37. Permanently Magnetized Armature.—It is a well-known fact that similar magnetic poles repel each other, and dissimilar magnetic poles attract each other. In Fig. 16 (*a*) and (*b*) is shown a bar of soft iron bent so as to bring the two ends opposite each other. Around each end of the iron bar is wound a coil of insulated wire, the two coils being wound in the same direction around the iron and connected in series with each other and with a battery B, as shown. When a current from the battery circulates in the direction of the arrows shown in (*a*), the current in each coil will magnetize the iron in the

same direction, and thus produce magnetic lines of force in the direction of the dotted arrows, and, consequently, a north pole at *N* and a south pole at *S*. If a permanently magnetized piece of steel is suspended so that its north pole *n* is free to move between the poles of the electromagnet, the south pole *S* of the electromagnet will attract the north pole *n* of the permanent magnet, and the north pole *N* of the electromagnet will repel the north pole *n* of the permanent magnet. Consequently, the north pole *n* of the permanent magnet will move over as near to the south pole *S* as the stop *e* will permit. If the battery and, as a result, the direction of current is reversed

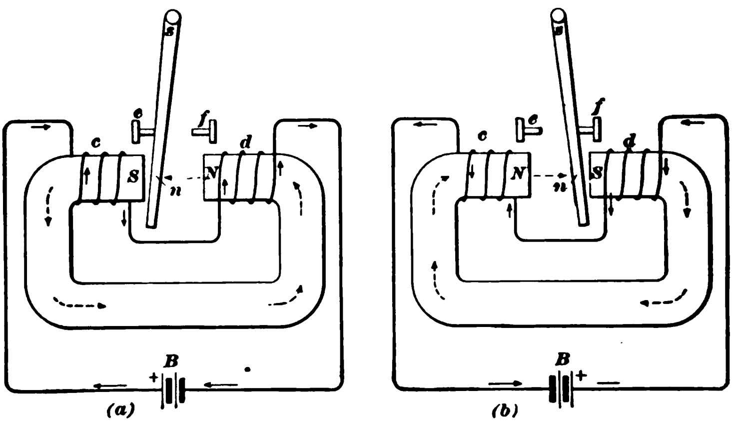


FIG. 16

in the coils, the lines of force in the soft iron and the polarities of the ends of the soft-iron core will be reversed, as shown in (*b*). Now the north pole *n* of the permanent magnet, being attracted by the south pole *S* and repelled by the north pole *N* of the electromagnet, will move from the stop *e*, as shown in (*a*), to the stop *f*, as shown in (*b*). If the current is reversed, the permanent magnet will move back to *e*. Thus every time the direction of the current is reversed, the permanent magnet, or **armature**, as it is called, will move from one stop to the other.

38. Permanent Magnet of Polarized Relay.—In order to keep the armature permanently and strongly magnetized,

and in order to otherwise increase the efficiency of the instrument, the polarized relay has a strong and rather large permanent magnet. A skeleton view of one form of a polarized relay is shown in Fig. 17. The curved piece P of special magnet steel has a very strong coercive force and is, therefore, quite permanent and not easily weakened or demagnetized. In its rear end, an armature, or **tongue**, as it is also called, is loosely pivoted, and on the front end is placed a piece of iron of about the same shape as that shown in Fig. 16. This rectangular piece and the tongue are made of the very best quality of magnetically soft iron. On the ends, or cores, of the soft-iron piece are wound the coils c and d. If the rear end of the permanent magnet is a north pole n, and the front end a south pole s, then when there is no current flowing in either coil, the soft-iron parts will be magnetized on account of their contact with the permanent magnet, so as to have north and south poles where indicated by the letters N and S, respectively.

39. The dotted arrows indicate the direction of the lines of force through the various parts of the magnetic circuit. In Fig. 17 (a), the lines of force are due entirely to the permanent magnet. If the tongue, whose forward end has north polarity, is exactly half way between the faces of the iron cores, it should, theoretically, remain there because each core, which has south polarity, will attract it with exactly the same force. But the least deviation in the equality of these two forces, due to the least deviation of the tongue from the exact middle position, will cause the tongue to fly against the stop e or f, toward whichever one the pull is the greater. To get the tongue to remain in an intermediate position, where the two forces are exactly in equilibrium is about as difficult as to stand an ordinary egg on its end.

40. Suppose that current flows through the coils c and d, as shown in Fig. 17 (b). This current through the coils in the direction shown will tend to make the right-hand end of the core, over which coil c is wound, a south pole S, but the permanent magnet, also, tends to make this end a south pole; hence, it becomes a stronger south pole than when there is no

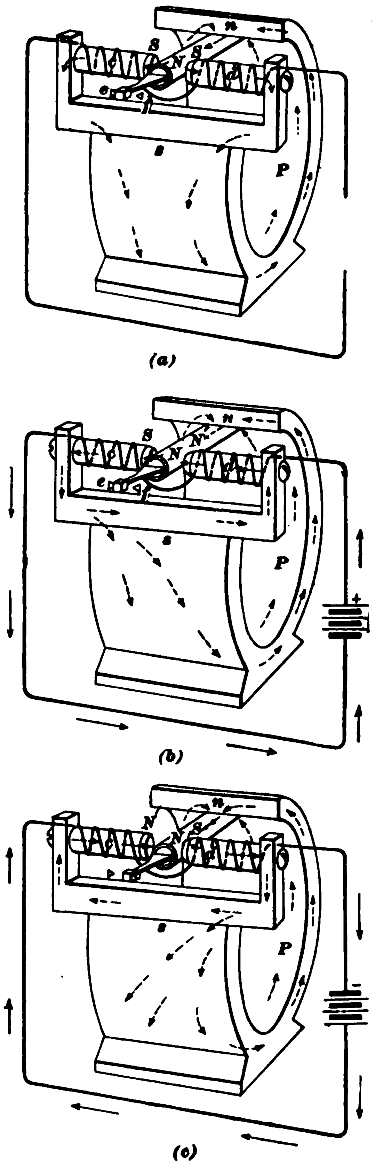


Fig. 17

current flowing through c. This same current tends to make the left-hand end of the core, over which d is wound, a north pole, but the permanent magnet tends to make it a south pole; hence, it becomes either a very much weaker south pole, or a north pole N', as here indicated. It is not, however, so strong a north pole as the right-hand end of the opposite core is a south pole. The result of these changes in polarities will be to create a strong attraction between the pole S and the armature N and a weaker repelling action between the armature N and the core N'. Hence, the two cores no longer oppose each other, but both tend to move the tongue in the same direction.

If the tongue was originally against the stop f, it will now move over against the other stop e and remain there even after the current is stopped. For the iron will return to its normal magnetic state when the current is stopped, as shown in (a), in which the opposite ends of both cores become south poles again and, therefore, attract the tongue. But the attractive force of each core for the tongue varies

inversely as the square of the distance between each core and the tongue; hence, the core that is the nearer to the tongue attracts it with a very much greater force than the more distant core, and the tongue is consequently held firmly against the stop *e*.

If the current is reversed in direction, the magnetic condition will be as represented in (*c*) and the tongue will move from the stop *e* over against the other stop *f*, because the south pole *S* attracts and the north pole *N'* repels the armature *N*. Thus a reversal of the current will move the tongue from one side to the other.

41. Advantages of Polarized Relays.—A polarized relay is a very efficient instrument. In the first place there is no spring to oppose the motion of the tongue or armature. Then the force that moves the tongue in one direction is exactly equal to the force that moves it in the opposite direction, because the current has the same strength in both directions. If the current in one direction weakens, it weakens equally in the opposite direction, and, hence, no adjustment is required for a variable current. Furthermore, the sending of reverse currents through the line tends to free the line more quickly of electrostatic charges and, consequently, allows more rapid sending. Polarized relays can be made exceedingly quick-acting and efficient.

42. In stormy weather a polarized relay will continue to give satisfactory service long after the ordinary, or neutral, relay becomes useless. This may be explained as follows: The pull between an armature and a core is proportional to the square of the number of lines of force per square inch at the pole face. For example, if there are 200 lines of force per square inch through the armature, or tongue, of the polarized relay due to the permanent magnet alone, only half of these will go from the armature, when in its middle position, through each core, making a density, say, of 100 lines at the polar surface. Should the normal current produce in each core a density of 200 lines of force per square inch, the total density in one core will be $100+200=300$, and in the other $200-100=100$,

hence, the force of attraction toward one core may be represented by $300 \times 300 = 90{,}000$, and the repelling force of the other core may be represented by $100 \times 100 = 10{,}000$, giving a resultant pull of 100,000. If in wet weather the effective lines of force produced by the current are reduced to 100, the pull toward one side will be represented by $(100+100)^2 = 40{,}000$ and the repulsion from the other side by $(100-100)^2 = 0$, giving a resultant force toward one side of 40,000. The resultant force has, therefore, diminished from 100,000 to 40,000.

43. In order to get the same normal pull in the neutral as in the polarized relay, let the number of lines of force set up in the neutral relay by the normal current be 223.6. Then, in fair weather, the pull between one core and the armature will be represented by $(223.6)^2$, and between the armature and both cores twice this amount, or $2 \times (223.6)^2 = 100{,}000$. Thus the neutral relay is not as efficient even in fair weather, for in order to get the same pull, it must have enough ampere-turns to develop 223.6 lines per square inch, whereas the polarized relay requires only enough to develop 200 lines. If, as before, it is assumed that in wet weather the effective number of lines of force is reduced to one-half its fair-weather value, that is, to 111.8, the pull will be represented by $2 \times (111.8)^2 = 25{,}998$.

44. In the polarized relay the pull is reduced from 100,000 to 40,000, whereas in the neutral relay, the pull is reduced from 100,000 to 25,998. Thus, in wet weather, the neutral relay exerts a pull of only a little more than one-half that exerted by the polarized relay. The less the effective current, the better does the polarized relay appear in the comparison with the neutral relay, for it always has the permanent magnetism to assist the variable magnetism. Furthermore, if the force that moves the tongue in one direction decreases or increases, the force that moves it back again in the opposite direction also decreases or increases, respectively, by exactly the same amount, and, therefore, there is no retractile force to readjust. The tongue may be pulled hard one moment and lightly the next, but it will still move across the gap, and that

is all that is required. Thus the detrimental effect of an extra flow of current due to leaks in wet weather is almost eliminated, because no matter how much or how little current is flowing, its direction can be reversed, and it is on these alterations in the direction of the current that the operation of the polarized relay depends.

45. An objection to the ordinary relay is the fact that the current through the relay will vary in strength due to variation in the line resistance and in the leakage to earth in wet and dry weather; consequently, there is a variable magnetic force working against the constant pull of a spring requiring a frequent readjustment of the spring or of the cores of the magnet or of both. The polarized relay, on the other hand, has no spring for the electromagnet to overcome, and, moreover, the action of the cores on the armatures is a double one, they being attracted and repelled at the same time. No alteration in the adjustment is required (except, perhaps, to counteract earth currents, not leakage currents, which must also be done in using the ordinary relay) to meet varying strengths of line current, and for this reason the polarized relay has considerable advantage over the ordinary relay.

WESTERN UNION POLARIZED RELAY

46. In Fig. 18 is shown a polarized relay that for many years was the standard of the Western Union Telegraph Company. The permanent steel magnet *M* is circular in shape and 3½ inches in diameter at the widest part. The two coils *c* and *d* are wound upon soft-iron cores between which the armature, or tongue *e*, made of a soft-iron tube, moves. This armature, which is 2½ inches long, is loosely pivoted at the rear. The supports *p* and *o* for the front and rear contact screws *a* and *b*, respectively, form part of a piece that can be moved a limited distance horizontally inside the cylinder *h* by the screw *k*.

The play of the armature is usually adjusted by the screw *a*, and the armature is *centered* by means of the screw *k*. To

center the armature of a polarized relay is to place it so that it can move an equal distance on each side of a point exactly midway between the faces of the two soft-iron cores. The

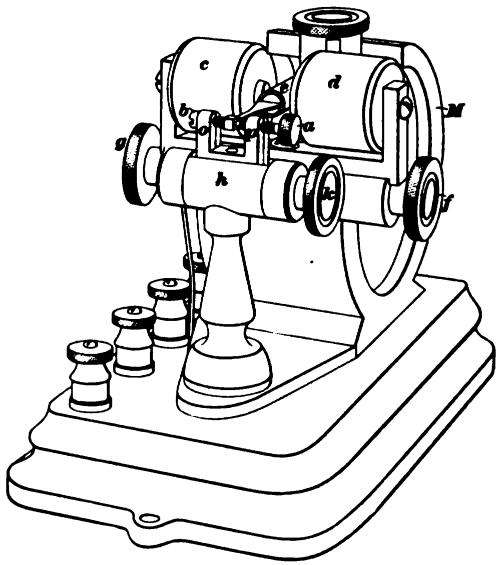


FIG. 18

cores, over which the coils *c* and *d* are wound, can be moved to and from the armature by the screws *f* and *g*.

STANDARD WESTERN UNION POLARIZED RELAY

47. The Western Union Telegraph Company has replaced many of the polarized relays just described by the improved and so-called *flat-pattern*, or Frier polarized relay shown in Fig. 19. In this connection it may be well to state that in relays and other apparatus of the same nature, the moving parts are being made light by the liberal use of aluminum, and quick-acting by the absence of iron yokes and a better arrangement of the iron parts.

In Fig. 19 (*x*) the instrument is shown complete, with part of one side cut away so that the arrangement of the parts inside

can be readily seen. The plan view (y) shows the permanent horseshoe magnet $N\ A\ S$, the two coils h and i, and the four soft-iron pole pieces s, n, s', and n' that project from the soft-iron cores to which they are fastened. The two soft-iron armatures stand in a vertical position between the pole pieces. The armature frame is shown separately in (z); it consists of two soft-iron armatures S' and N' held together by an aluminum frame o.

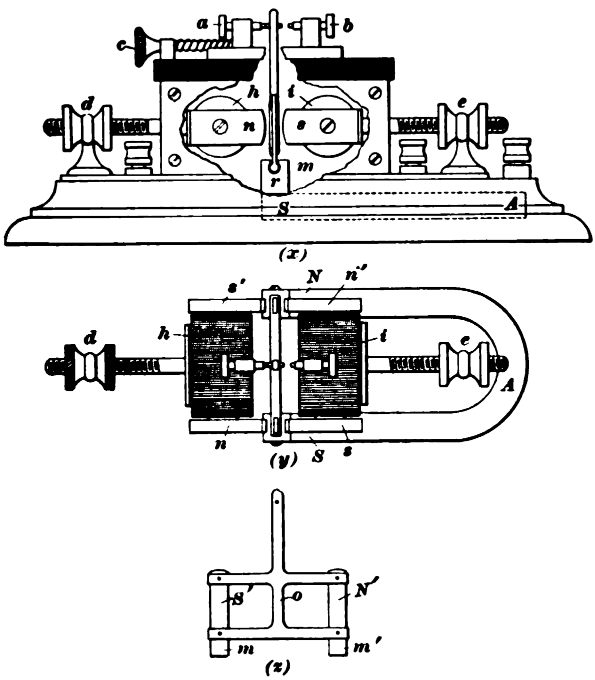


FIG. 19

48. The permanent magnet $N\ A\ S$ lies flat in the base of the instrument. Each pole of this magnet has a short iron extension r, in a recess in which the lower ends m and m' of the vertical iron armatures S' and N' loosely rest. The iron armatures are polarized by the permanent magnet. If the permanent magnet has a north pole at N and a south pole at S, the armature will be polarized as indicated by the letters

S' and N', assuming that one end m rests in the extension piece r fastened to the south pole S of the permanent magnet, and the other end m_1 in the extension of the north pole N. Each iron armature extends up between two of the core pole pieces, as shown in (x). Both armatures are attracted toward the same side by the two pole pieces attached to opposite ends of the same core and both are repelled in the same direction by the two pole pieces attached to opposite ends of the other core.

When a current circulates in one direction through the coils, the core extensions will have the polarities indicated. When the current is reversed, the polarities of all four core extensions are reversed. Thus twice as many poles are utilized in this instrument as in the older type. Furthermore, the cores are not connected by any yoke, so that the relay responds more quickly to a change in the current.

49. The cores, coils, and pole pieces may be moved toward or away from the armatures by the screws d and e. The front and back stop-screws a and b are mounted on a frame that can be moved as a whole by the screw c. As much of the relay as may be convenient is placed in a brass case with a hard-rubber top in order to protect it from dirt and injury. However, there is left just enough of an opening in the side to allow the armatures and the core extensions to be readily seen.

The coils are usually wound differentially in sections, half of each differential winding being wound on each core. Each section contains about 2,850 turns of No. 36 B. & S. wire having a resistance of 200 ohms, thus making 400 ohms and 928 feet in each differential winding. When wound with enameled wire the relay has about the same number of turns, but the resistance is reduced to 300 ohms, due to the thinner insulation and the larger size wire that can be consequently used.

THEORETICAL CONNECTIONS OF DOUBLE-CURRENT SYSTEMS

50. The use of polarized relays for simplex working is illustrated in Fig. 20, where two terminal and one intermediate offices are shown. Here PR represent polarized relays and K

double-current transmitting keys. The key at each station normally rests on the backstop *c*, and the switch *l* normally connects stop *c* with contact *a*. In this position all batteries are cut out of the line circuit, resembling in this respect the Morse open-circuit system. When an operator wishes to send, he moves the switch *l* so as to connect the backstop *c* with contact *b*, as shown at station *E*. With the key resting on the backstop *c*, negative current flows from station *E* to station *W* through the line wire, causing each polarized relay to hold its armature against the backstop *f*, thus keeping the local-sounder circuits open. When the key *K* is depressed, the negative charge on the line is first neutralized by a positive charge from the battery *B*; then the current rises to its maximum value,

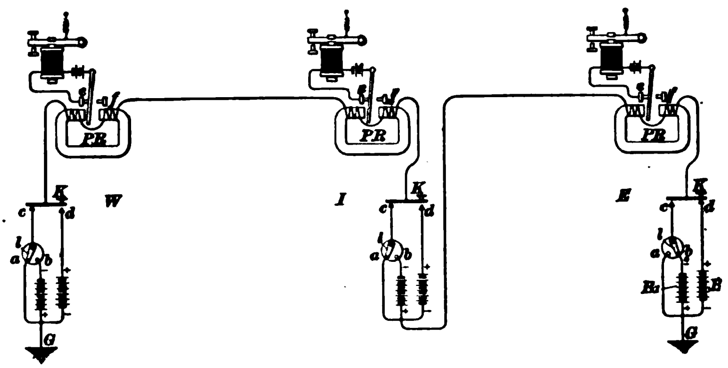


Fig. 20

and a positive current flows from station *E* to station *W* through the line, causing each polarized relay to move its armature against the front stop *e*. This closes the local-sounder circuits and sooner than would be the case if the single-current system were used. Current will continue to flow in the local-sounder circuits not only until the key *K* breaks away from the front stop *d*, but until it touches the backstop *c*. Then a negative current first having neutralized or cleared out the positive charge, flows from station *E* to station *W* through the line and polarized relays and opens the local circuits.

51. In single-current systems, a current in one direction causes dots and dashes and no current produces the spaces.

In double-current systems it is evident that starting a current in one direction starts a dot or dash, and a current in the opposite direction is required to terminate the dot or dash and start a space. The key here shown requires two batteries at each station, but there are keys, which will be shown later, that in one position connect the positive pole of a battery to the line and the negative pole to the earth, and in the other position will reverse the connections of the same battery so that the negative pole of the battery is put to the line and the positive pole to the earth. Such a key requires only one battery.

52. Polarized Relays as Represented in Diagrams. In Fig. 21 are shown three additional ways in which polarized

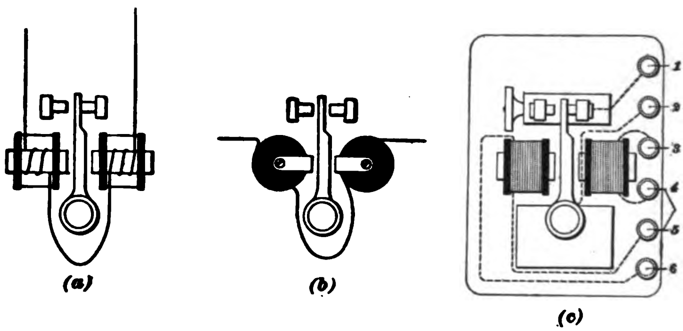


FIG. 21

relays are represented; whenever any one of these occurs in a diagram hereafter, it should be immediately recognized as a polarized relay. The way in which the polarized relay was drawn in Fig. 20 and in (*a*) and (*b*) in Fig. 21 are conventional diagrams; (*c*) is a plan view of the older type of Western Union polarized relay, showing six binding posts. Numbers *1* and *2* are the binding posts to which the local-sounder circuit is connected. Binding posts *3*, *4*, *5*, and *6* are the terminals of the four ends of the two coils. For use as a simple polar relay, binding posts *4* and *5* are connected together by a short stout wire and binding posts *3* and *6* form the two line terminals of the instrument. The use of the binding posts *4* and *5* will be apparent when the polar duplex and quadruplex systems are described.

53. Polarized Relay Used as a Single-Current Relay.—A polarized relay may be adjusted so that it will close the local-sounder circuit when the main-line current flows through it in one direction and open the local circuit when the main-line current is interrupted. That is, it may be used in place of an ordinary relay. To use it in this way, the two stops *a* and *b* in Fig. 19 must be so adjusted that the whole play of the armature is on one side of the middle point between the two soft-iron cores. Then, when no current flows, the armature will always be drawn, due to the normal magnetic polarity of the cores produced by the permanent magnet, to the nearer core and the corresponding stop. When the key is closed, the current, in order to send a dot or dash, must circulate in such a direction around the cores as to reverse the normal polarity of the other core. Then when current flows, the two cores will combine to move the armature toward the middle, but the one stop is so adjusted that the armature cannot pass or even quite reach this middle position, and, consequently, as soon as the current stops, the armature flies back toward the nearer pole, and against the corresponding stop. Thus the making and breaking of a current, which must flow in one particular direction with reference to the direction of the winding on the polarized relay, will move the armature and so open and close the local-sounder circuit.

POWER EQUIPMENT

(PART 1)

DYNAMOS

INTRODUCTION

1. Modern telephone practice involves the use of electric currents in so many ways and in such considerable quantities that quite an elaborate power plant is now necessary for the successful operation of a telephone system. While the individual units are usually not large, they must be of considerable number to furnish the different kinds of currents required.

In central-energy systems, electric current is used for two purposes; namely, to supply the talking circuits and to perform the function of signaling. For energizing the transmitters, direct current is invariably used, it being taken usually from storage batteries, which have been found to be the most satisfactory source of current not only for all the transmitters but also for the operation of relays, magnets, and miniature lamps used as signals. Storage batteries have been fully considered elsewhere. For ringing the subscribers' bells, some form of alternating or interrupted current is generally used.

2. A **dynamo** is a machine for converting the mechanical energy furnished by a steam engine, waterwheel, or other prime mover into electrical energy by electromagnetic

induction. Dynamos may be divided into two general types, depending on the character of their currents. These two types are:

1. *Continuous-current* or *direct-current dynamos*, in which the current through the external circuit flows continuously in the same direction.

2. *Alternating-current dynamos*, the current from which periodically alternates or reverses in direction and usually with great rapidity. A common frequency for alternating-current dynamos used for incandescent lighting is 60 cycles per second, but they may be designed to give almost any desired frequency.

3. Advantages of Dynamos.—Dynamos and storage batteries are rapidly replacing primary batteries, because they are generally more economical. It is generally most economical to use dynamos as a source of current supply; next in order of economy come rotary converters or dynamotors, motor-dynamos, and then storage batteries, and, finally, primary cells. Mr. Preece, when head of the telegraph and telephone systems of the British Government, stated that, for telegraph and telephone purposes, electricity produced by primary batteries cost $1.50 per kilowatt-hour, as against 2 cents by the system in which dynamos and storage cells are used. The relative cost is doubtless as much in favor of the dynamo and storage battery in other countries as in England. Furthermore, primary cells must be periodically replenished or renewed and require continual inspection and attention in order that they may be kept in good condition and their electromotive force even approximately constant.

4. Essential Parts of a Dynamo or Motor.—The parts of an ordinary dynamo or motor may be summarized as follows: (1) As complete a circuit of iron as possible. Such a circuit is composed of the cores of an electromagnet, usually an iron yoke or base connecting the cores, and the cylindrical or ring-shaped core of an armature that revolves between the magnet ends or poles, which are shaped so as to partly embrace the armature. This iron circuit is shown

in Fig. 1. *C*, *C* are the iron cores, *A* the iron part of the armature, and *M* the iron yoke. (2) Coils of insulated wire *W* wound around the field-magnet cores *C*, *C*. When a current flows through these coils, magnetic lines of force are set up through the iron circuit. The dotted lines represent the path and the arrows represent the direction of the magnetic lines, or *flux*, as they are called. (3) Coils of insulated wire, wound on the iron armature core but carefully insulated from it. When the armature core and coils are rotated between the pole pieces *S* and *N*, the coils cut the magnetic lines of force and develop an electromotive force. (4) A collecting mechanism, called the *commutator* in a direct-current machine and *collector rings* in an alternating-current machine. The commutator or collector rings are attached to, but insulated from, the armature shaft and rotate with it. The collecting mechanism consists of these rings or segments of rings, to which the wire coils of the armature are connected and on which press copper or carbon pieces called *brushes*.

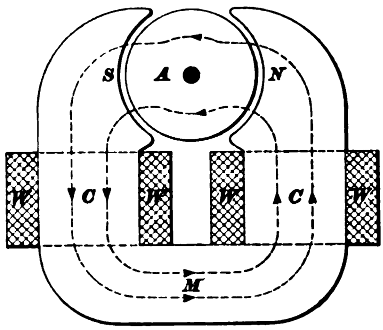


FIG. 1

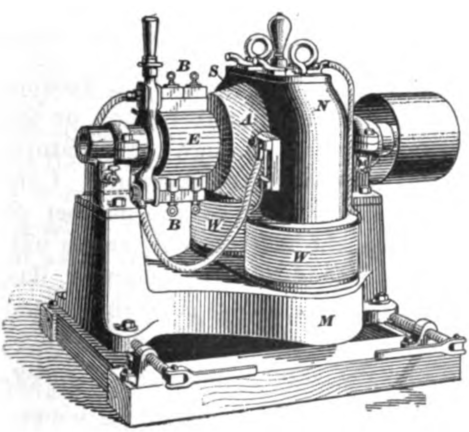


FIG. 2

5. In Fig. 2, *E* represents the commutator and *B*, *B* the brushes of a direct-current dynamo or motor. This is rather

an old type but is used here as it shows the various parts better than a more modern enclosed type of machine, which will be illustrated presently. When used as a dynamo, the electromotive force developed by the cutting of the magnetic lines of force by the wires on the armature shows itself as a difference of potential between the brushes. This difference of potential at the brushes or at the terminals of the machine, to which the brushes are directly connected, usually by short heavy wires or bars, is called the **voltage** of the dynamo, because it is measured in volts.

If the two brushes B, B on opposite sides of the commutator E are connected with some circuit external to the machine, the potential difference will cause a current to flow in that circuit. By using enough coils on the armature and properly divided and connected segments on the commutator, the current may be made to flow always in one direction, giving a practically continuous current; such a machine is called a **direct-current dynamo.** If only two collecting rings are used, the current flows first in one direction and then in the opposite direction; such a machine is called an **alternating-current dynamo.**

6. The potential difference at the brushes of a dynamo depends on the speed at which the armature rotates, on the strength of the magnetic flux passing through the armature, and on the number of turns of wire on the armature. Consequently, with a given machine in which the number of turns on the armature is fixed, the voltage will remain uniform, provided that both the speed and the magnetic flux remain constant. The speed is usually constant within about 2 per cent. By regulating the current in the field coils, the magnetic flux may be varied, and, consequently, the voltage can be regulated.

7. Methods of Exciting the Field.—The requisite number of ampere-turns for exciting the field of a dynamo-electric machine may be obtained in a variety of ways. In the first place, the current that flows through the magnetizing coils may come either from some separate external source,

the machine being then said to be *separately excited*, or it may be furnished by the armature of the machine itself, it being then said to be *self-excited*. In some cases, a combination of these two methods may be used.

DIRECT-CURRENT DYNAMOS

SEPARATELY EXCITED DYNAMOS

8. A **separately excited dynamo** is so named from the fact that its field magnets are excited or magnetized by a current from some external source, as, for instance, a voltaic battery or another continuous-current dynamo. The connections of a separately excited dynamo are represented in Fig. 3. The magnetizing coils are wound around the cores of a magnet and connected to the terminals of a voltaic battery *B*. The exciting current flows from the battery around the cores of the field magnet in such a direction as to set up lines of force through the armature, and has no connection whatever with the current obtained from the brushes by rotating the armature. If the strength of the exciting current is not changed, the difference of potential between the brushes of the dynamo, when the armature is rotated at a uniform speed, remains constant as long as the external circuit is open; but when the external circuit is closed, the difference of potential gradually diminishes as the strength of the current increases, owing to the internal resistance of the armature conductors and the reactions of

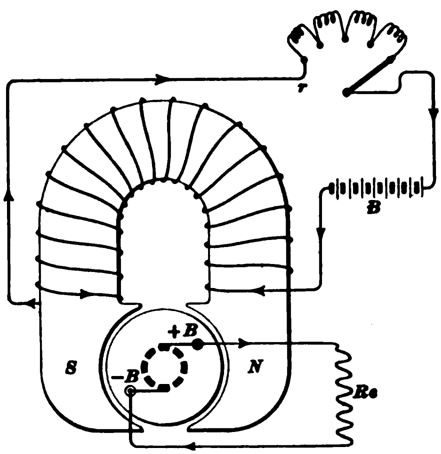


FIG. 3

the armature current on the field. An explanation of this can be found in a treatise on the theory of dynamos, but it would require more space than is advisable to devote to it here.

SELF-EXCITED DYNAMOS

9. A **self-excited dynamo** is so named from the fact that the exciting current for the field magnet is furnished by the dynamo itself. There are three methods of self-exciting a dynamo.

1. The field coils may be connected across the brushes in shunt with the external circuit; such a machine is called a *shunt dynamo.*

2. The field coils may be connected in series with the external circuit and the armature; this is called a *series-dynamo.*

3. The field may have two distinct windings on it, one of which is connected across the terminals or brushes and in shunt with the external circuit, and the other in series with the external circuit and the armature; this is called a *compound*, or a *shunt-and-series dynamo.*

10. Shunt Dynamo.—In Fig. 4 is shown a **shunt dynamo.** One terminal of the magnetizing coil is connected to the positive brush and the other to a terminal mounted on the field rheostat r; the negative brush is connected to the arm of the field rheostat. If the resistance of the rheostat is neglected or cut out, it will be seen that the total difference of potential exists between the terminals of the magnetizing coils when the dynamo is generating its maximum electromotive force. The magnetizing coils of a shunt dynamo, however, consist of a large number of turns of fine copper wire, thus making the resistance large in comparison with the difference of potential between the field terminals. In well-designed dynamos, the resistance of the shunt coil is large enough to allow not more than about 5 per cent. of the total current of the dynamo to pass through the field coils. According to Ohm's law, the strength of current, in

amperes, circulating around the field coils is equal to the difference of potential, in volts, between the brushes, divided by the sum of the resistances, in ohms, in the field coil and in the rheostat *r*. Since the total resistance in the field circuit is large compared with the voltage between the

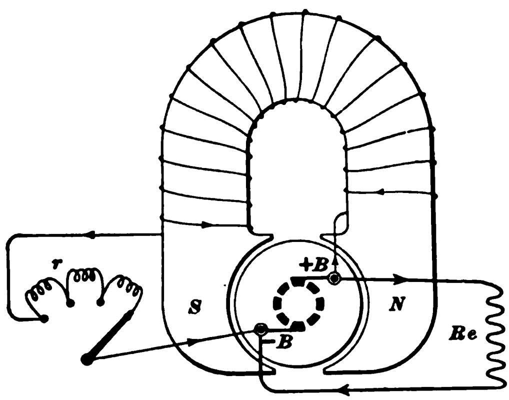


FIG. 4

brushes $+B$ and $-B$, the current in the field coils will be relatively very small compared to the total current as just stated.

11. Regulation of a Shunt Dynamo.—The difference of potential between the brushes of a shunt dynamo gradually decreases as the current from the armature becomes stronger, on account of the internal resistance of the armature conductors and the reactions of the current on the field. Any decrease in the difference of potential between the brushes causes a corresponding decrease in potential at the field terminals, thereby weakening the current in the magnetizing coils. In order to compensate for the decrease in the difference of potential at the brushes, a field rheostat *r* of comparatively high resistance is connected in the field circuit, and is so adjusted that when no current is flowing in the external circuit, only enough current flows through the field to produce the normal difference of potential between the brushes. This normal difference of potential between the brushes is kept

constant, as the load increases, by gradually cutting out, or short-circuiting, the resistance coils of the rheostat.

As the resistance in the rheostat is decreased, more current flows through the field coils, thus increasing the flux or strength of the field; this, in turn, causes an increase in the electromotive force generated in the armature, provided, of course, that the speed remains the same. If there is an appreciable change in the voltage at the terminals of the dynamo when running, it is the dynamo attendant's business to keep this voltage constant within prescribed limits by properly adjusting the field rheostat.

12. The shunt dynamo is very extensively used. Fig. 2 shows an old type of shunt dynamo mounted on sliding rails, which are attached to a wooden bedplate. Two adjusting screws, one on each side of the machine, are used to move the dynamo along the rails, thereby loosening or tightening the belt, as the circumstances may require. The current passes from the brush holders through flexible copper cables to two terminals fastened to, but insulated from, the pole pieces; from the terminals, the current divides, a small portion passing through the field coils and the rheostat, which is not shown in this figure, and the rest through the external circuit.

An incandescent lamp is often connected between the main terminals of the connection board, and is used to indicate when the machine is generating its normal electromotive force. A lamp used for this purpose is often called a **pilot lamp**.

13. Series-Dynamo.—Fig. 5 shows a **series-dynamo.** The magnetizing coils of a series-dynamo are connected directly in *series* with the external circuit; that is, all the current from the armature circulates around the magnetizing coils and flows through the external circuit. The connections of a series-dynamo are shown in the figure. The current starts from the positive brush $+B$, circulates around the external circuit Re, thence through the magnetizing coils back to the negative brush $-B$. The action

of a series-dynamo differs widely from that of a shunt dynamo. The difference of potential between the brushes depends on the strength of the current flowing from the armature, but it is not necessarily directly proportional to the strength of the current. Compared with the coils on a shunt dynamo, the magnetizing coils of a series-dynamo are made of a few turns of a large conductor. This is necessary, because the coils are usually required to carry the total current from the armature; the conductor is made large to carry the current without heating, and only a few turns are necessary to secure the proper magnetizing force.

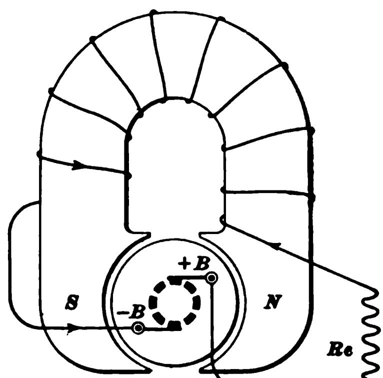


FIG. 5

14. Compound Dynamo.—In the shunt dynamo previously described, the regulation of the difference of potential at the terminals of the machine is not automatic; it is accomplished by a mechanical movement of an arm or contact. This movement of the rheostat arm is sometimes imparted automatically by a magnet controlled by the current in the external circuit. But, more often, when a very constant potential is desired, it is automatically regulated in the dynamo itself by a combination of the *shunt* and *series* magnetizing coils; such machines are termed **compound dynamos.**

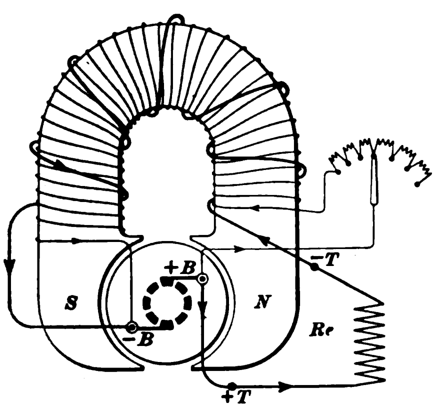


FIG. 6

In Fig. 6, the shunt coils consist of a large number of turns of fine insulated wire wound on the core of the magnet. The series-coils, consisting of a few turns of large insulated wire, are wound over or alongside the shunt coils. The main part of the current from the armature flows from the positive brush $+B$ through the external circuit Re, thence through the series-coils to the negative brush $-B$. The shunt coils and an adjustable resistance are connected to the two brushes $+B$ and $-B$. But the series and shunt coils are so wound that the currents in both will circulate around the core of the magnet in the same direction when they are connected as shown in the diagram. The action of both currents, therefore, is to produce the same polarity in the magnet, the shunt current being reenforced by the series-current. When the dynamo is not loaded, that is, when no current is flowing in the external circuit and the armature is rotated at normal speed, the normal electromotive force is generated in the armature due to the magnetic field produced by the shunt coils alone. On closing the external circuit, however, the difference of potential between the brushes tends to decrease, and it would continue to decrease, as previously described in a simple shunt machine, if the series-coils were neglected. The current circulating through these, however, reenforces the magnetizing force of the shunt coils, and immediately increases the number of lines of force in the field, which, in turn, raise the difference of potential between the brushes to normal. These actions are produced simultaneously, and, to all appearances, the difference of potential between the brushes remains normal for nearly all changes of load in the external circuit. This method of regulating the difference of potential at the terminals of a dynamo is called **compounding**.

15. The **terminals** of a dynamo are the binding posts to which the external circuit is connected. In a series, or compound, dynamo, one terminal is attached to the outside end of the series-coils, as $-T$ in Fig. 6, and the other terminal $+T$ is connected directly to the brush $+B$. In a

compound dynamo, the shunt field and adjustable resistance are usually connected directly across the brushes.

16. Direct-current dynamos may be subdivided into two classes, as follows:

1. *Constant-potential dynamos*, in which the difference of potential at the terminals of the machine remains constant and the strength of current changes with the load or external resistance. The word *load* is a common expression for current in dynamos generating a constant potential. Strictly speaking, however, the load means the product of the current and the voltage, but the voltage is considered constant and, therefore, the load is directly proportional to the current. That is, if the current in the external circuit is doubled, the load is doubled.

Constant-potential dynamos should be started and brought up to full speed and normal voltage with the main switch connecting the external circuit open, that is, before any load is put on the machine. It is preferable to apply the load gradually and not all at once.

2. *Constant-current dynamos*, in which the strength of current (continuous, pulsating, or alternating) remains constant and the difference of potential at the terminals of the machine changes with the load.

Compound, separately excited, and shunt dynamos are included under the first head, and rank in their ability to maintain a constant potential in the order named and for reasons already explained.

Constant-current dynamos have usually a series-field, and at present are used almost exclusively for operating continuous- or direct-current arc lamps.

17. Currents furnished by dynamos for charging storage batteries in telephone exchanges should preferably be as smooth and continuous as possible, that is, they should closely resemble the continuous non-pulsatory current obtained from batteries. In order to obtain such smooth currents from dynamo-electric machines, it is best to have a smooth, iron, armature body on which to wind the wire and

a commutator with a large number of segments (at least 48). The revolving armature and commutator should run at a fairly high speed. Armatures with the wires wound in slots produce a current more pulsatory in character, and are sometimes very troublesome to grounded telephone systems, whose wires run near and parallel, even for a short distance, to other wires that are supplied with currents from such armatures.

ALTERNATING-CURRENT DYNAMOS

18. Alternating-current dynamos are used for generating ordinary ringing currents. The fields of alternating-current dynamos are usually separately excited, either from a direct-current dynamo or from storage batteries. A large alternating dynamo usually has a small direct-current machine

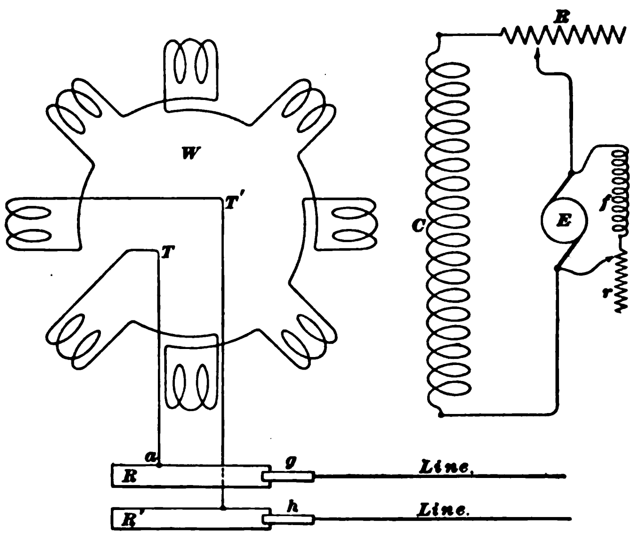


FIG. 7

associated with it for exciting its field. In Fig. 7 is shown a diagram of connections of a simple alternating-current dynamo with a much smaller direct-current machine for exciting the alternator fields. *W* represents the armature winding of the alternator, the terminals *T*, *T'* of which are

connected to the collecting rings R, R', which make contact with the line wires by means of the brushes g, h. The field is excited by a set of coils on the pole pieces represented by C, and the current is supplied to these from a small direct-current dynamo, or exciter, E. This is a small shunt-wound machine with an adjustable field rheostat r in series with its shunt field f. An adjustable rheostat R is also placed in the alternator field circuit. When the voltage drops or rises, the fields may be strengthened or weakened by adjusting the resistances R and r; thus, the voltage may be kept right.

By means of a commutator mounted on the shaft of the alternator alongside the slip rings some of the current generated in the armature may be rectified, that is, converted into a direct current, and passed through a series-winding on the field. The arrangement accomplishes about the same purpose as the compound winding of a direct-current dynamo, that is, the alternating-current voltage increases with the load enough to keep the voltage at some point on the line constant or nearly so.

SELECTION AND INSTALLATION

SELECTION

19. A few general principles in regard to the selection of dynamos and motors apply to almost all cases. The construction of the machine should be first class in every respect. There should be evident solidity, each part being amply large to insure durability and as simple as possible; complicated parts are almost sure to cause trouble and expense. Machines in which careless workmanship, defective material, or poor finish are evident should be avoided. If there is danger of mechanical injury from foreign substances falling against the rotating parts, the machines should be provided with perforated doors or covers so arranged as to furnish the necessary mechanical protection and at the same time allow all possible ventilation. Electric machines for use in a damp atmosphere

or one filled with dust or small flying particles of any kind should be entirely enclosed, dust- and moisture-proof, with suitable doors, or covers, for inspecting the working parts. This class includes motors for installation in mines, rolling mills, forge rooms, carbon works, cement works, etc.

The machine selected should be of ample size for the work required and its construction, both mechanically and electrically, should be such as to require the least possible care and attention. The first cost of such a machine is not often of so great importance as is the cost of care and insurance against breakdowns and repair bills.

20. The losses occurring in electrical machinery are mostly converted into heat, which raises the temperature of the surrounding parts. In the purchase of such machinery, it is important that the temperature rise, as well as the sparking and overload conditions, be fully specified. It is not best to specify to manufacturers of electrical machinery many of the details of construction; the conditions to be met should be clearly stated and the specifications strictly enforced.

Finally, it is best always to deal with manufacturers of established reputation and to purchase machines so well standardized that duplicate repair parts can be quickly and easily obtained. Moreover, such concerns always keep in their employ competent engineers who will give valuable advice as to an installation on which they are permitted to bid.

INSTALLATION

21. Location.—The machine should be located in a clean, dry, cool place, protected from the dropping of water from steam and water pipes or from the roof. A space surrounding the machine, especially around the commutator and brushes, should be clean and free from all obstructions. If the machine is controlled from a switchboard, the operator should be able to reach the board without going through a belt or over other obstructions. Dust from the street is injurious to the commutator, bearings, and general insulation

of electrical machines, but dust from a coal pile or any kind of grinding or turning machine is even more so because it is often more adhesive, or sharper and more gritty.

22. **Foundations.**—Every machine of 25 horsepower, or more, should be provided with a substantial foundation. In order to avoid communicating to the building the vibrations incidental to the running of the machine, this foundation should, if possible, be independent of the floor and walls of the building in which it is installed. If several machines are to be installed in the same room, it will be best to have the whole floor space concreted and covered with a layer of cement or a wooden floor; but for a single machine or a group of small machines, it will be sufficient to make the foundation slightly larger than the floor area. In any case, stonework, solid brickwork, or concrete is the best foundation; but where these are impracticable, a substantial wooden frame construction can be used. When a concrete or brick foundation is used, it is customary to cap this with a hardwood frame, coated with a high-grade insulating compound of some sort; the layer of wood serves not only to insulate the metal frame of the machine from the ground, but it acts to cushion the blows and lessen the vibration due to the machine.

Insurance underwriters have established certain rules, known as the **National Code Rules,** for installing electrical machinery, wires, etc. to which all such installations must conform before the buildings containing them are insurable against loss by fire.

If the machine is belt-driven, means should be provided for tightening or slacking the belt. This is usually accomplished by mounting the machine on rails or on a subbase and moving it by means of a ratchet lever and screw. The foundation should in every case be so disposed that the distance between the centers of the driving and driven shafts will allow one side of the belt to run looser than the other. This distance should be at least four times the diameter of the larger pulley. The loose side of the belt should be on top

and the driving side below, as this will increase the arc of contact and the driving power of the belt.

23. Erection.—Small machines are usually shipped complete and ready to run, so that it is only necessary to set them in place and make the necessary connections. Large machines cannot be shipped, with safety, in an assembled condition, and are, therefore, dismounted and the parts marked and packed in separate parcels. The assembling of the parts should not be undertaken by one wholly unfamiliar with such work, and even an expert must follow closely the blueprints and the marks on the parts.

Too much caution cannot be used when handling such machinery, to see that it is not injured. A slight bruise or scratch on a journal or bearing or a bruised oil ring may result in much annoyance and, possibly, expense. Especial care is needed when handling the field coils and the armature; it is imperative that these be not bruised or the insulation abraded in any way. The commutator is very sensitive to pressure or blows and should be shielded from them in every way possible.

OPERATION OF DIRECT-CURRENT DYNAMOS

24. Dynamo-electric machines and all devices connected with their operation or regulation should be kept scrupulously clean. No copper or carbon dust, dirt, grease, or oil should be allowed to remain on any part of the machine. If available, a jet of compressed air should frequently be used to blow all loose dust out of the commutators, armatures, field coils, etc. If this cannot be done, a good hand bellows should be used. Not only the machines themselves but all their surroundings should be kept perfectly clean and free from rubbish or litter. The appearance of the dynamo room, as well as that of the machines, indicates the alertness of the attendants and the probable attention given the whole plant. Continual watchfulness is necessary to discover any possible defect before it has developed sufficiently to cause serious trouble. It is well to follow a definite system of

inspecting and caring for electrical machinery. Each part should be systematically examined, and cleaned or repaired if necessary, at regular intervals. If this is done, there will be less chance of overlooking or forgetting anything, and expensive delays or repairs may be avoided.

25. Starting a Dynamo.—Care must be taken to have the machine in perfect order mechancially before starting it. Turn the armature slowly by hand to see that it does not rub nor bind at any point. Put on the belt, with the minimum distance between pulleys. See that all loose articles are removed from the machine. A good rule is never to allow a loose article of any kind to be placed on any portion of a dynamo. Start the machine slowly and see that the oil rings rotate. When everything seems to be running smoothly and easily and without undue noise or vibration, gradually bring the machine up to speed and allow it to develop its normal electromotive force. If a belt is used, tighten it until it runs steadily and without flopping and allow the machine to run several hours without load. If the windings have been exposed to dampness, it might be well to run at slow speed and a reduced voltage for a time, thus allowing the passage of sufficient current to dry out the moisture. After everything is in perfect order and the windings are thoroughly dried, the speed and the load may be gradually increased until the desired capacity is reached.

26. Field rheostats consist of a resistance so arranged that it can be cut in or out of a circuit by steps. The resistance material may consist of German silver, iron, or other material, or sometimes of cast-iron grids. Wire or strip resistance is usually wound or assembled on an insulating support of some kind and afterwards covered with an insulating and heat-conducting material. The total resistance should be about the same as that of the field to be controlled and of sufficient current capacity to carry the largest field current indefinitely without overheating.

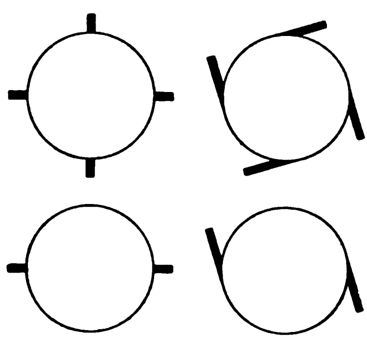
27. Knife switches should be substantially constructed, with blades preferably of drawn copper and the clips stiff

enough to give good firm contact when fully closed; they should have ample current-carrying capacity, so as not to overheat, and be capable of breaking the largest current through the circuit without destructive burning or arcing. Plain knife switches are generally used for pressures up to 1,000 volts; above that and even above 500 volts, it is better to use some kind of a quick-break switch. Switches on a vertical surface should be mounted with the handles up when the switch is closed, so that, when open, the switch will not tend to fall closed.

INDIVIDUAL PARTS OF MACHINES—THEIR DEFECTS AND REMEDIES

BRUSHES AND BRUSH HOLDERS

28. On direct-current machines, the brushes and commutator require, perhaps, more attention than all the other parts of the machine. Brushes are of two kinds: *radial* and *tangential*. **Radial brushes,** Fig. 8 (*a*), point straight toward the center of the commutator. **Tangential brushes,** Fig. 8 (*b*), frequently made of copper, are found, as a rule, only on low-voltage high-current machines. Radial brushes are nearly always made of carbon and are always used on machines designed to rotate in either direction. The brushes should be so placed that with a slight end play of the armature the whole commutator surface will be utilized.



(*a*) (*b*)

FIG. 8

The pressure with which a brush should bear on the commutator depends on the material and condition of the

commutator and the material of the brush itself. A copper brush does not, as a rule, require as much pressure as a carbon brush, and soft carbon will run with less pressure than hard carbon. Good practice is from $1\frac{1}{2}$ to 2 pounds per square inch. Pressures greater than 2 pounds per square inch are seldom necessary except where there is excessive vibration, as on railway motors. Increasing the pressure beyond what is necessary to maintain good contact, only results in increasing the friction, with consequent heating and wear.

29. **Carbon brushes** are made in several grades of hardness, adapted to different conditions of working and different kinds of commutators. High-voltage machines usually require harder carbons than low-voltage machines. There are so many conditions affecting commutators that it is extremely difficult to specify the grade of carbon most suitable for a particular machine. The carbon must not be so hard as to scratch the commutator nor so soft as to cover it with smut. Harder carbons are generally used on electric-locomotive and electric-car motors than for stationary work.

Carbon brushes may be given a good bearing surface on the commutator by sliding a piece of fine sandpaper back and forth between the brush and the commutator, with the rough side next to the brush. Do not use emery paper on the brushes or the commutator, as emery is a conductor and may cause short circuits between adjacent commutator bars. Moreover, particles of emery sticking to the face of the brush, being more gritty than sand, will scratch the commutator.

30. Examine the brushes frequently to see that they have full bearing surface and that the surface is smooth and glossy. If it is raw, grayish in color, rough, and gritty, or if it is covered with particles or streaks of copper, something is wrong. Sometimes conditions can be improved by changing the brush lead, that is, shifting the brushes, and often considerable relief can be had by boiling the brushes

in vaseline. To do this place the brushes in a vessel with sufficient melted vaseline to cover them and boil for about 1 hour, after which remove the brushes and wipe them dry. If there is time, let them stand in an oven or other warm place for a few hours and wipe off all surplus grease before replacing them in the holders.

31. Metallic brushes are made of strips of copper, bundles of copper wires, or, more frequently, copper gauze folded into shape and stitched. Those made of strips or wires are very liable to have the edges or ends of the laminæ fused together by sparking, forming hard points that cut the commutator. Whenever this occurs, they should be taken out and the ends trimmed off. To get them to the proper level, so that they will rest evenly on the commutator at the proper angle, it is customary to use a filing jig, as shown in Fig. 9. This consists of a block of steel with a hole through it the size of the brush, and with one end beveled off to the proper angle and hardened. The brush is placed in the jig with the end projecting a little from the beveled face, and clamped in position. The end of the brush may then be filed or ground down flush with the face of the jig, thus giving it the correct bevel.

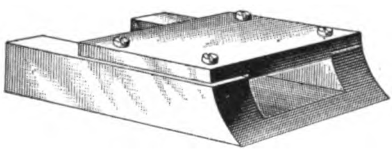


FIG. 9

Metallic brushes should not be allowed to become filled with oil or dirt; if they get in this condition, they may be readily cleaned with benzine or kerosene.

32. Brush Holders.—The moving parts of the brush holders should be as light as is consistent with strength and there should be no stiffness or rigidity to prevent the brush from closely following any unevenness in the commutator. If carbon brushes are used, the brush, as it wears off, should move toward the center of the commutator and the pressure of the brush spring should remain practically constant until the brush is worn out. To prevent a tendency to chatter, or jump from the commutator, the brush holders

should be set as near the commutator as possible. These points regarding brush holders are determined by the manufacturer, but will guide in selecting a machine.

THE COMMUTATOR

33. The **commutator** is the most sensitive part of a machine, and its faults are liable to develop more quickly than those of any other part. When a commutator is in the best possible condition, it assumes a dark-chocolate color, is smooth, or glazed, to the touch, and causes the brushes, if of carbon, to emit a characteristic, squeaky noise when the machine is turning slowly. Oil should be used very sparingly, if at all, on a commutator; to lubricate it, put a film of vaseline on a canvas cloth, fold the cloth once, and let the commutator get only what oil goes through the pores. Too much oil or grease will cause arcing or flashing at the brushes and black rings will form around the commutator. These should be wiped off with clean cloth. Never use waste to wipe the commutator or brushes and the cloth used should be as free as possible from lint.

34. **Roughness** of the commutator may be due to overloads, to improper setting of the brushes, to poor workmanship or material, or to defective design. For occasional slight roughness due to either of the first two causes, sandpaper may be used; but if the condition keeps recurring and seems to be due to either of the last two causes or to some other cause not readily ascertained, some more permanent remedy must be used.

Before using sandpaper remove the brushes or fasten them back where they will be out of the way. Hold the sandpaper on the rotating commutator with a segment of wood having the same radius as the commutator. Use No. 2 sandpaper at first and finish with No. 0. For a final polish reverse the paper and hold the smooth side next the commutator for a moment. Blow all dust out of the machine as soon as the operation is completed.

35. Stoning.—Frequently, a commutator that appears very rough may be placed in a satisfactory condition by a process called **stoning**. A block of sandstone 4 inches square and 8 inches long can be placed in a wooden holder of convenient shape and size and one of the long surfaces made to fit the curvature of the commutator. Grinding a commutator with a stone made in this way is preferable to using sandpaper, for the stone will not dip into low places but will grind the high bars only. If the stone is coarse, it may be desirable to finish the commutator with fine sandpaper. The stone will not reduce the diameter of the commutator, or the radial wearing depth of the bars as much as a turning tool.

36. Eccentricity.—If a commutator is not properly baked during construction or is not screwed down after it is baked, it is liable to bulge out in the course of time under the action of the heat due to its normal load and the action of centrifugal force, or it may develop loose bars. In the case of the bulging of one side, sandpaper will not do any good. The best thing to do with such a commutator is to take it off, bake it so as to loosen the insulation, tighten it up well, and turn it off in the lathe. For ordinary unevenness of surface of large commutators due to wear, it is customary to set up a tool post and a slide rest on the bedplate of the machine itself and turn off the commutator while in position. Commutator turning tools that may be readily attached to almost any large dynamo or motor are supplied by many leading manufacturers of electrical machinery.

37. High or Low Bars.—If, when a commutator is rotated slowly, a sharp metallic click is heard as many times per revolution as there are brush holders and a slight jumping of a brush is noticed every time the click is heard, there is probably one or more high or low bars. If it is a high bar and if it is tight in the commutator, the material in the bar is probably too hard; the bar may be dressed down with a file while the armature is standing still. A low bar may be due to soft material, to bad sparking caused by a defect in the armature winding, to a careless blow, or the bar may be

loose. If due to any of the first three causes, the armature surface should be turned down in a lathe or with a commutator turning tool to the level of the low bar. If due to the second cause, the defect in the winding should also be found and removed. A loose bar, either high or low, will necessitate a thorough repair job. After turning a commutator always finish with No. 0 sandpaper as directed in Art. **34.** Inspect the surface closely to see that no burrs bridging across the mica have been left by the tool.

38. The most serious condition is to have an armature or a commutator that is defective in design or that contains defective material or workmanship. If the design is poor, it may be very difficult or even impossible to keep the commutator in good condition. If the mica is too soft, it will pit out between the bars leaving a trough to fill up with carbon dust and thus short-circuit the neighboring armature coils. If the mica bodies are too hard or too thick, the bars will wear in ruts and require frequent turning down.

THE ARMATURE

39. Heating.—An armature should run without excessive heating; if it heats so as to smoke or give off an odor, the machine should be shut down at once and the cause of the heating should be located and removed. The odor of overheated insulation is very peculiar and easily recognized, especially after having once experienced it. The heating may be caused by damp insulation—a condition that, as a rule, is shown by steaming, but which can be better determined by measuring the insulation to the shaft with a voltmeter. If low insulation is indicated, the armature should be baked, either in an oven or by means of a current passed through it in series with a lamp bank or water resistance, or as directed in Art. **25.** The baking current should not exceed the full-load current of the machine. If, while the machine is at rest, a current for baking purposes be sent through the armature from an external source, be sure that

the series-field, if the machine has one, is not included in the circuit, and that the shunt field is broken; for if either field is on, the machine may start up as a motor.

40. Short Circuits.—If, instead of the whole armature running hot, the heat is confined to one or two coils, there is probably a short circuit either in a coil or between the two commutator bars to which the ends of the coil connect. If a short-circuited coil is run in a full-excited field, it will soon burn out. A short circuit of this kind can be readily detected by holding an iron nail or a pocket knife up to the head of the armature while it is running in a field. Any existing short circuits in the coils or commutator will cause the piece of iron to vibrate very perceptibly; each time the defect passes underneath. If the trouble is confined to one or two coils, it can frequently be located by stopping the machine after running a few moments and feeling the armature all over for the hot coil.

If one or more coil connections are reversed on one side of a dynamo armature, that side will generate less electromotive force than the other, and hence, will receive current from the other side; that is, a current will flow through the armature coils that does not flow through the external circuit. This current is useless and heats the machine unnecessarily. If the same mistake is made in connecting a motor armature, the side having the reversed connections will generate less counter electromotive force than the other side and will therefore receive more than its share of the current flowing through the motor, making this side overheat.

41. A **flying cross** in an armature is a defect caused by a loose or broken wire with poor insulation; when the armature is standing still or even when it is rotating much below its standard speed, the wire may remain so nearly in place that the defect cannot be noticed; but when full speed is attained, centrifugal force throws the wire out of place and into contact with other wires or with the core or framework of the machine causing sometimes severe sparking or flashing. Such a defect is often very hard to find; some of

the tests given in Art. 40 may assist in locating it, or it may be necessary to give the whole armature winding a minute inspection.

42. Overloaded Armatures.—One of the most common causes of general trouble and heating in an armature is **overload**; this may be due to ignorance or neglect or to an error in the instrument that measures the load. There is a great tendency on the part of owners to gradually increase the load on a machine until it may be doing much more than the work for which it was designed. By adding lamps, one or two at a time, it is an easy matter to unwittingly overload a dynamo. Or in the case of a motor, small devices may be added, one at a time, until an overload is the result. Ammeters sometimes get out of order, read incorrectly, or stick, and thus do not indicate the full load of the machine.

FIELD-COIL DEFECTS

43. Open Circuits.—Among **field-coil defects** are *open circuits*, *short circuits*, *grounds*, and *wrong connections*.

An **open circuit**, or a break, occurring in the field circuit of a dynamo or a motor when the machine is idle, will usually be discovered on attempting to start up, before any further injury has resulted. If the break occurs while the machine is in service, the field magnetism will be lost with results more or less disastrous, depending on the style of winding, the work the machine is doing, and whether it is operating alone or with other machines. For example, if the break occurs in the shunt-field winding of a shunt- or a compound-wound dynamo, operating alone, the machine will merely cease to generate; if operating in parallel with other dynamos, the other machines will be short-circuited through its armature with the possible burning out of some or all of the dynamo armatures on the circuit. A shunt motor will cease to generate counter electromotive force, and its armature will become a short circuit across the line and will be burned out unless the armature circuit is opened almost

immediately. Application of the principles governing the generation of an electromotive force will enable one to determine the result of a break in the field circuit under conditions other than those given.

44. Short Circuits.—The effect of a short circuit in a field coil depends on the kind of machine and the method of field connection. If the defect occurs in a shunt field, there will be an increased field current and but very little change in the speed of a motor or in the electromotive force of a dynamo. If a series-field is short-circuited, the effect in a dynamo is to reduce the electromotive force and in a motor to increase the speed; hence, if the electromotive force of a dynamo becomes too low or the speed of a series- or a compound-wound dynamo becomes too high and the change cannot be otherwise accounted for, it is probable that the series-field has become short-circuited.

Short circuits may be caused by carelessness in winding or in handling, by defective insulation, or by moisture. By far the larger part of such defects are probably due to moisture absorbed by the insulating materials when the machines are idle for some time, especially if they are in a damp place. This moisture should be baked out either in an oven or by allowing a small current to flow through the coils for some time, increasing gradually to the normal current as the coils become dried. If very moist, the coils should be baked in an oven before a current is sent through them.

45. Grounds, or Connections Between Windings and the Field Frame.—In circuits, neither side of which is permanently grounded, an accidental grounding of the windings will produce no further immediate injury to the machine, provided that the ground be removed at once; but if it be allowed to remain until a second one occurs, the two may have the effect of a short circuit. On electric-railway circuits, however, where one terminal of the dynamo is permanently grounded to the rails, a single ground on the windings will usually have the effect of a short circuit.

46. Wrong Connections.—One or more field coils may be connected so that the current flows through them in the wrong direction, or the series and shunt coils of a compound-wound machine may be connected **differentially**, that is, so that they oppose each other in effect, when they were intended to be connected **cumulatively**, that is, so that they would assist each other in magnetizing the fields. It is a good plan, when connecting up a machine, to try the poles with a compass when the fields are excited, to see that the north and south poles alternate and the series and shunt fields, if both are used, are connected in the right direction with respect to each other.

REASONS FOR A DIRECT-CURRENT DYNAMO FAILING TO GENERATE

47. Among the causes for a dynamo failing to generate may be given, loss of residual magnetism; wrong connections of field or armature; open circuits or poor connections; short circuits; low speed; magnetic-circuit defects, which may consist of bad flaws or blowholes in the field casting or poor magnetic joints; wrong position of the brushes, etc. Some of these causes may result in a decreased voltage instead of a complete failure to generate.

48. Loss of Residual Magnetism.—Of all the causes that may make a dynamo fail to generate, the loss of residual magnetism, or **charge**, is one of the most troublesome. As a rule, dynamos leaving the factory retain enough residual magnetism to start on, but there are several ways in which they can lose it. Some dynamos never lose their charge, while others are continually doing so.

49. When a dynamo has lost its charge, the pole pieces have little or no attraction for a piece of soft iron. Series-dynamos seldom lose their charge so entirely that they fail to pick up a field when short-circuited. When a compound-wound dynamo refuses to generate its normal electromotive force with its shunt winding, it can often be made to pick up

by disconnecting the shunt coils and short-circuiting the machine through a small fuse. Machines can in some cases be made to pick up a field by simply rocking the brushes back from their neutral position.

50. If these expedients fail to produce the desired result, the fields must be recharged from an outside source. If the dynamo runs in multiple with other dynamos, it is only necessary to lift the brushes or disconnect one of the brush-holder cables on the dead machine and throw in the main-line switch, the same as if the machine were going into service with the others. The fields will then take a charge from the line and their polarity will be correct. If the dynamo does not run in multiple with another and there is a dynamo or storage battery within wiring distance, disconnect the shunt field of the dead dynamo and connect it to the live circuit. If there are absolutely no other means available for charging, several ordinary battery cells may be used. As a last resource, when all other available sources fail, connect the fields so as to obtain the least possible resistance, put them in series with the armature through a small fuse, and speed the armature considerably above the normal rate.

Sometimes a dynamo, instead of losing its residual magnetism, will acquire one of a reversed polarity, for which it is difficult to give a cause that will be generally applicable. In this case, the dynamo will build up with the polarity of the brushes reversed. In some cases, this would do no harm; but in most cases, it is essential that the brush polarity be always the same; and if the dynamo begins to build up wrongly, it is best to stop it at once and ascertain the cause. If it be found that the residual magnetism is reversed, an external electromotive force should be applied, to restore the fields to their proper direction.

51. Wrong Connection of Field or Armature.—In the process of building up the field of a dynamo, it is essential that the very slight electromotive force due to the armature conductors cutting the residual magnetism shall send current around the field coils in such a direction as to add to

the residual magnetism. If the reverse were true, all the magnetism would be killed and the dynamo would fail to generate. It follows then that, after a dynamo has been left charged in one direction, if its field or armature leads are reversed, the machine will not pick up; and, if it be run long with these wrong connections, the residual magnetism will be completely lost and the machine will fail to pick up, even when the connections are made right again, until the fields have been recharged.

52. Again, one or more field coils may be incorrectly put on, or connected so that they oppose each other. On a compound-wound dynamo, the reversal of a shunt-field coil will generally keep the dynamo from picking up on open circuit, unless the dynamo has more than four coils; the more coils it has, the less effect will the reversal of a single coil have. The reversal of a series-coil is not felt until an attempt is made to load the machine; the voltage will not come up to where it should for a given load, and the brushes are apt to spark on account of the weakened field.

53. Open Circuits or Poor Connections.—A shunt or compound-wound dynamo will not pick up if the shunt-field circuit is open; the open circuit may be in the field itself, in the field rheostat, or in some of the wires or connections in the circuit. A careful inspection will generally disclose any fault that may exist in a wire or connection. To find out if the rheostat is at fault, short-circuit it with a piece of copper wire; if the dynamo generates with the rheostat cut out, the fault is in the rheostat. A field circuit is sometimes held open by a defective field switch that is apparently all right; repeated burning may have oxidized the tip of the switch blade and formed on it a non-conducting blister, which prevents the jaws of the switch from coming into electrical contact with the blades. Another trivial but common cause of open circuits is the blowing of fuses.

An open circuit in an armature will interfere with the proper generation of electromotive force, but such a fault, as a rule, announces its own occurrence and location in a very

emphatic manner: there will be severe sparking and the commutator bars to which the open coil is connected will be badly burned in a short time.

Before attributing the failure to generate to any of the foregoing open-circuit causes, see that the brushes are on the commutator, the field switch closed, and the greater part of the field rheostat cut out. The electromotive force generated when a machine is first started is very small, because the residual magnetism is weak. It may not require a complete open circuit in a field to prevent a machine picking up. A bad contact that might not interfere with the working of the machine when it is up to full voltage may be sufficient to prevent its picking up when first started. A loose shunt wire in a binding post or a dirty commutator may introduce sufficient resistance to prevent the machine from operating. Trouble is very often experienced in making machines with carbon brushes pick up, especially if the brushes or commutator are at all greasy. If such is the case, clean the commutator thoroughly, wipe the ends of the brushes with benzine, and see that they make a good contact with the commutator surface.

54. Short Circuits.—A short circuit occurring on the main line of a shunt dynamo while the machine is running will cause it to lose its field; therefore, the machine will not pick up if its line is short-circuited. A short circuit on the line of a series-wound or a compound-wound dynamo increases its ability to pick up, because the fault is in series with the series-coils and a large current passes through them. A series-dynamo cannot pick up with its external circuit open because no current can flow through its field coils. Either a series or a shunt dynamo may not pick up if its field is short-circuited. A compound-wound dynamo may not pick up on open circuit if the shunt field is short-circuited; if the series-coils only are short-circuited, the machine will pick up with the main circuit open, but will not hold its voltage when the current begins to flow. In some cases, a shunt dynamo will not develop its normal

electromotive force on full load, as this approaches too nearly the condition of a short circuit; so that to be on the safe side, it is best to let the machine build up its field before closing the line switch.

Short circuits within the dynamo itself generally give rise to indications that point out the location and nature of the fault. In any event, the first thing to find out is whether the fault is in the dynamo or out on the line; if the machine picks up its field when the line switch is opened, but fails to do so when it is closed, the trouble is on the line.

55. Low Speed.—A dynamo will not pick up its field when running below a certain speed, but with the field once established, the machine will hold it at a much lower speed than that required to pick it up. The speed at which a series-dynamo will pick up depends on the resistance of the external circuit.

SPARKING AT THE COMMUTATOR

56. Probably the most troublesome and annoying feature in the operation of direct-current dynamos and motors is **sparking at the commutator.** The cause is not always apparent, but it may usually be found among the following: Too much load; brushes improperly set; commutator rough or eccentric; high or low bars; sprung armature shaft; brushes making poor contact; dirty brushes or commutator; too high speed; low bearings; worn commutator; short-circuited or reversed armature coil; open-circuited armature; vibration; belt slipping; weak field; grounds.

57. An **overloaded armature** heats all over. The sparking may be lessened but not stopped by shifting the brushes ahead on a dynamo and back on a motor. If the machine is a motor, the speed will be low; if a dynamo, the voltage will be below the normal amount, unless the machine is heavily overcompounded.

58. Brushes may be improperly set in either of two ways: They may be the right distance apart but too far one way or the other as a whole; this can, of course, be remedied

by shifting the rocker-arm back and forth until the neutral point is found. The brushes may, as a whole, be central on the commutator, but the spacing between adjacent holder studs be wrong; count the commutator bars between adjacent sets of brush holders and adjust the spacing until the number of bars between each pair is the same.

59. Poor Contact.—The brushes may make poor contact due to a brush being stuck in a holder so that the spring does not force it down on to the commutator; to the temper being out of the spring; to the pressure of the spring not being brought to bear directly on the brush; to the brush not fitting the commutator surface, etc.

Dirty brushes or commutator may cause the brushes to make poor contact. Some carbon brushes contain paraffin placed in them for lubricating purposes. When the brushes are hot, the paraffin may run out too rapidly and cover the commutator with a greasy smut, which insulates it in spots. Copper brushes sometimes get clogged with oil, dust, and bits of lint or waste. Dirty commutators are usually the result of using too soft brushes, or too much oil, or frayed cloths or waste in cleaning.

60. Too high speed is apt to make a machine spark, because it increases the voltage induced in the armature coils as each coil is momentarily short-circuited by a brush. **Worn bearings** sometimes throw the armature far enough out of the center to distort the field and cause sparking. A **badly worn commutator,** even if otherwise in good condition, seems inclined to spark in spite of everything that can be done—it may be because, as the bars grow shorter by wearing away, they become thinner and the brushes then span too many bars, in which case a thinner brush may give relief; or it may be because the error in the angle of the holder increases with the distance from the commutator.

61. Either a short-circuited or a reversed armature coil will cause a local current that will increase the power required to run either a dynamo or a motor, even without any load. A motor will run with a jerky motion, especially

noticeable at low speeds, and a dynamo will cause the needle of the voltmeter connected to its terminals to fluctuate. In either case, unless the cross that causes the trouble is removed, the coil will burn out.

By an **open-circuited armature** is meant a break in one of the armature wires or its connections. Excessive current may burn off one of the wires or a bruise of some kind may nick a wire so that the normal load, or perhaps less, burns it off. A commutator may become loose and break off one or more leads. Sometimes, on account of excessive heating, the armature throws solder and all the commutator connections become impaired; in such a case, while there may be no actual open circuits, there are poor contacts that result in making the commutator rough and black.

62. **Vibration** of a dynamo or a motor will cause constant sparking even at very light loads. The vibration may be due to a poor foundation or to a poorly balanced armature; the remedy is to place the machine on a firmer foundation or to properly balance the armature. A **slipping belt** will sometimes cause intermittent sparking because it subjects the machine to unusual variations in speed.

63. Causes for **weak fields** have already been mentioned; viz., poor joints, either magnetic or electric, wrong connections, short circuits in series-fields, etc. A weak field is easily distorted by armature reaction until it may become impossible to shift the brushes to a point of sparkless commutation.

As in the case of field coils, a single ground on the armature windings of a railway generator, or any machine working on a permanently grounded circuit, will have the effect of a short circuit and will cause sparking and heating. When all wires connected to a dynamo are insulated, two grounds on the dynamo armature windings will cause more or less of a short circuit.

64. The causes of sparking thus far mentioned are such as may be due to improper treatment or abuse after a machine has left the factory, and not necessarily the result of faulty

design or construction. It sometimes happens, however, that notwithstanding a dynamo or motor receives only the best of care, it persists in sparking badly at full load or even less. This may be due to poor design, mechanically or electrically, something for which the attendant is not responsible, except possibly as the machine may be one of his selection.

65. A moderate amount of sparking at the commutator is not very objectionable, but, if it becomes sufficient in amount or in duration to blacken or roughen the commutator bars, the cause should be located and removed if possible. Numerous small white sparks, evenly distributed along the edge of the brush and producing no distinguishable noise, usually work little injury. Larger sparks, appearing at irregular intervals along the edge of the brush, usually with a greenish hue and accompanied by a hissing sound, are more serious. Such sparks usually cling tenaciously to one point on the brush edge, and they are due to small particles of copper, torn loose from the commutator by excessive local heat and which cling to the brush surface. On stopping the machine after running a few hours with this kind of sparking, a furrow, or strip, will be found cut into the commutator all around the circumference under the spot where the spark appeared. A well-designed, modern, direct-current dynamo or motor, with the brushes in one position, should be sparkless from no load to full load and possibly to 25 per cent. overload. There should be no injurious sparking at 50 per cent. overload and many manufacturers guarantee their machines to stand even 100 per cent. overload, momentarily, without injury.

TESTING FOR FAULTS

66. Many of the defects that are liable to develop in dynamo-electric machines are apparent from a mere inspection. Other defects, such as short-circuited or open-circuited field coils or armature coils, must be located by making tests. For tests of this kind, the Weston or similar instruments are most convenient if they have the proper range

for the work in hand. For measuring resistances, the *drop-of-potential method* is generally most easily applied. This method consists in sending a current measured by an ammeter through the resistance and measuring the drop of potential by a voltmeter or millivoltmeter between the terminals of the resistance; from the two readings the resistance is calculated. For measuring a very low resistance as, for example, that of an armature coil, the voltmeter must be capable of reading low, say to thousandths of a volt. A millivoltmeter will be best suited to this work.

67. Open-Circuited Field Coils.—If a dynamo fails to pick up and a voltmeter, connected across the brushes, shows a small deflection when the machine is running at full speed, the failure cannot be due to loss of residual magnetism. A careful examination will reveal any defective or loose connections between the coils. Quite frequently, the wire becomes broken at the point where the leads leave the spool, while the insulation remains intact, so that the break does not show. This may be detected by bending the leads to and fro.

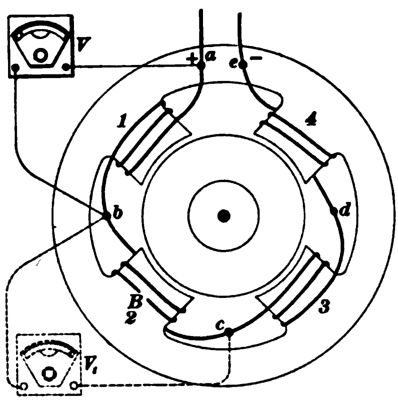


FIG. 10

If the break, however, is inside the winding of one of the coils, it can be detected only by testing each coil separately to see whether its circuit is complete. To do this, connect the field directly across the circuit of another dynamo, if one is available, as in Fig. 10, where the field terminals are connected at *a*, *e* to wires coming from another machine in operation or from a storage battery. If the field coils *1*, *2*, *3*, *4* are all perfect, a current will flow through them; but if one of them has a break in it, as at *B*, no current can flow.

To locate the defective coil, the terminals of a voltmeter are touched to the terminals of the different coils until the defective one is indicated by a deflection of the voltmeter needle. The needle will in each case indicate drop of potential. When the terminals are touched to terminals *a*, *b* of coil *1*, there will be no deflection of the needle because no current is flowing through coil *1*, hence there is no drop of potential in the coil. When the voltmeter terminals are touched to terminals *b*, *c* of the defective coil, as indicated by dotted lines, it is connected through coil *1* to the positive side of the circuit and through coils *3* and *4* to the negative side; hence, it will measure the full pressure of the circuit connected to *a*, *e*.

If a dynamo or storage battery is not available for making the test, a common battery and a bell in series, or a magneto-generator and bell may be substituted for the voltmeter. It is evident that if connections are made at the terminals *a*, *b* of coil *1*, or those of any other perfect coil, the bell will ring but, if made at *b*, *c*, or at the terminals of any other coil containing a break, there will be no ring.

68. Short-Circuited Field Coil.—If the windings of a field coil become short-circuited, either by its wires coming in contact with each other or by the insulation becoming carbonized, the defective coil will show a much lower resistance than it should. The drop of potential across each of the various field coils should be about the same, so that if one coil shows a much lower drop than the others, it indicates a short circuit of some kind. The short-circuited coil will usually run cooler and all the others warmer than normal.

69. Grounds Between Winding and Frame.—After a machine has thoroughly warmed up for the first time after being installed, and at frequent intervals thereafter, it should be tested for grounds. This may best be done with a good high-resistance voltmeter, as follows: While the machine is running, connect one terminal of the voltmeter to one terminal of the dynamo and the other terminal of the voltmeter to the frame of the machine, as shown in Fig. 11, where

T and T_1 are the terminals of the dynamo and V and V_1 two positions of the voltmeter, connected as described.

If, in either position, the voltmeter is deflected, it indicates that the field winding is grounded somewhere near the other terminal of the dynamo; that is, if the voltmeter at V shows a deflection, the machine is grounded near the terminal T_1, and vice versa. If the needle shows a deflection in both positions, but seems to vibrate or tremble, the armature or commutator is probably grounded. If, in either case, the deflection does not amount to more than about one-twentieth the total electromotive force of the machine, the ground is not serious; but if the deflection is much more

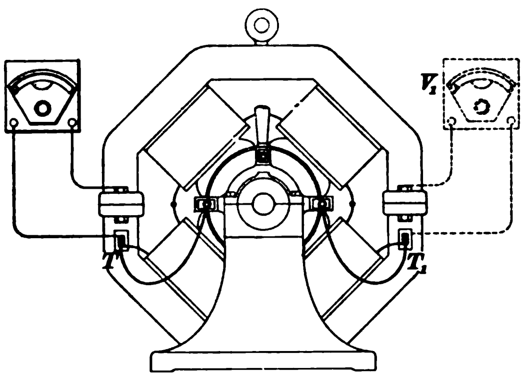


FIG. 11

than this, the windings should be examined separately, the ground located, and, if possible, removed. Before making this ground test on a railway or other permanently grounded dynamo, the grounded terminal should be disconnected from the circuit.

70. Locating a Ground.—Fig. 12 illustrates a method of testing to locate a ground. The machine is shut down and the electric circuit broken into as many distinct portions as possible; that is, each field coil is disconnected from its neighbors and the dynamo terminals T, T_1 are disconnected from the external circuit. C, C_1 are terminals of a live circuit of about the same difference of potential as the normal

voltage of the defective dynamo when running. One terminal C of the live circuit is connected to some bright surface on the frame (a bolt head in this case) where good contact can be had, and the other to a voltmeter V of sufficient capacity to measure the full electromotive force of circuit $C\,C_1$. The other voltmeter terminal is connected to successive field terminals t, t_1, etc. and, if need be, to the machine terminals T, T_1 or to the commutator. In each case, little or no deflection will be shown until connection is made to the defective portion of the circuit. In the figure, if the coil with terminal t_1 were grounded, the voltmeter would show a deflection. If the ground were complete, that is, a *dead ground*, the deflection would show the full voltage of the circuit $C\,C_1$.

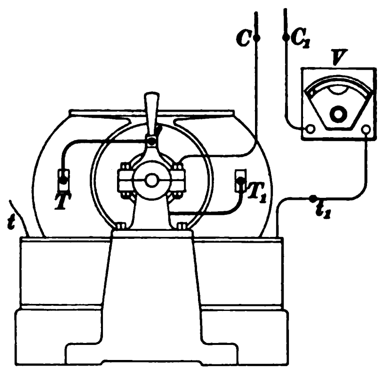


FIG. 12

71. Defects in the Armature.—Faults in the armature may best be located by what is known as the **bar-to-bar test,** connections for which are shown in Fig. 13. A current from an external circuit E is led through the armature by way of contacts A, B, which may be clamped to the commutator. A variable resistance, represented by the lamp bank $L\,B$, should be used to regulate the strength of this current. A millivoltmeter G is connected, through the commutator bars *1*, *2*, *3*, etc., successively, to the individual coils N, W, K, etc., by means of a contact maker, or crab, C, which is provided with two properly spaced contact pieces. Suppose, in this case, that the dynamo has three defects, which are as follows: (1) There is a break in coil T, which prevents any current flowing through the bottom coils between the contacts A, B, but all the current passes through the top coils; (2) there is a short circuit in coil N; (3) the commutator leads of coils S, K, W are mixed. All these defects are indicated in the figure.

72. The test is carried out as follows: Adjust the lamp bank until the voltmeter gives a good readable deflection when *C* is in contact with what are supposed to be good coils. The amount of current required in the main circuit will depend on the resistance of the armature under test. If the armature is of high resistance, a comparatively small current will give sufficient drop between the bars; if of low resistance, a large current will be necessary. With the contact maker *C*, the operator runs over several bars to obtain what is called the standard deflection with which to compare all the other deflections. The damaged part will often show a wide difference in deflection from the good coils. The deflection of the voltmeter will depend on the difference of potential between the bars. If everything is all right, the difference of potential between each pair of consecutive bars will be practically the same.

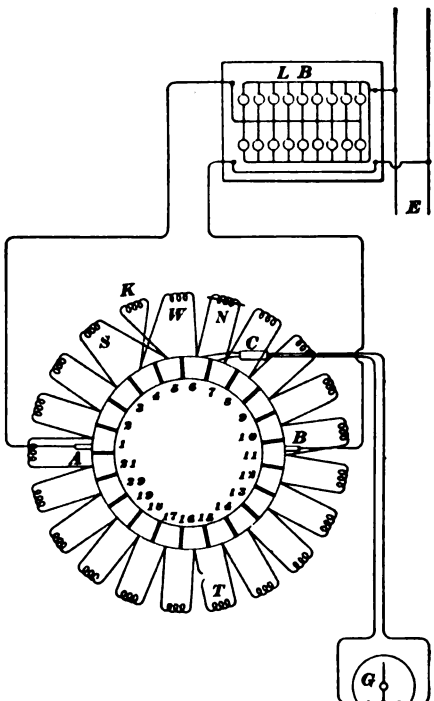


FIG. 13

No deflection will be obtained on the lower side, except when bars *15* and *16* are bridged. There will then be a violent throw of the needle, because the voltmeter will be connected to *A* and *B* through the intervening coils. The break is thus located in coil *T*. As a temporary remedy for this, bars *15* and *16* may be connected together by a jumper or piece of short wire. The defective coil *T* should, however, be repaired as soon as possible.

When the contact rests on bars *3* and *4*, a deflection about double the standard will be obtained, because two coils are connected between *3* and *4* in place of only one. When on *4* and *5*, the deflection will reverse, because the leads from *K*, *S* and *K*, *W* are crossed; but it will not be greater than the standard, because only one coil is connected between *4* and *5*. Between *5* and *6* as large a deflection will be obtained as between *3* and *4* and for the same reason. Between *6* and *7* little or no deflection will be obtained, because coil *N* is short-circuited, and hence there will be in it little or no drop.

If a coil has poor or loose connections with the commutator bars, the effect will be the same as if the coil had a higher resistance than it should, and hence the deflection will be above the normal. In practice, after one has become used to this test, faults may be located easily and rapidly. It is best to have two persons, one to move *C* and the other to watch the deflections of *G*.

REPAIRS

73. Field Coils.—In case of accidents to parts of the machinery, it is sometimes very convenient to make repairs on the spot, saving the time lost in sending the injured apparatus to the makers. There is usually no difficulty in rewinding field coils in a lathe. First weigh the old coil and, when removing the wire, note carefully the method of connecting, the size, and the insulation of the wire, and the insulation on the spool. When rewinding the coil, use exactly duplicate features, as nearly as possible, unless it be plainly evident that the conditions can be improved.

If necessary to make a joint in the wire, the ends of the wires should be rubbed bright with fine sandpaper, twisted firmly together, and soldered with a hot iron, using only resin as a flux. Only solder enough should be left on the joint to make the connection between the wires solid. Remove all projecting ends or bits of solder, leaving a perfectly smooth joint and one occupying as little space as possible. The joint should then be well insulated with silk, cotton, paper, or adhesive tape.

74. Armatures.—To rewind an armature, in whole or in part, is usually a much more difficult task; and if the job be of much importance, the advice or assistance of an experienced man should be obtained. If such work be attempted, proceed slowly, carefully noting connections, insulations, etc. in removing the old portion and duplicate all these features, as nearly as possible, in the new winding. When complete, the binding wires should be replaced, and the winding tested for grounds, before connecting it to the commutator. It will be well, while replacing the winding, to make frequent tests for grounds or short circuits.

When being replaced, binding wires should be subjected to a considerable tension, so that when they expand as the armature heats up they will not become loose. They should be soldered together quickly with a very hot iron, using, as before, only resin as a flux.

75. Balancing an Armature.—Many makers balance armatures by means of small masses of solder secured to the binding wires. If these binding wires are replaced, the armature must be rebalanced in order that it may run without excessive vibration. For this purpose, two iron or steel straightedges or ways, as shown in Fig. 14,

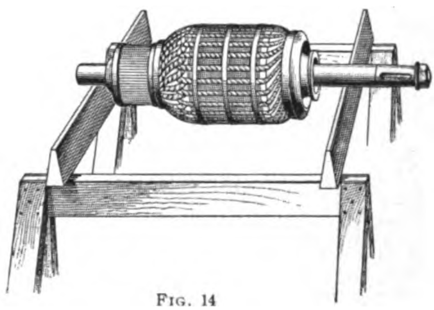


FIG. 14

should be provided. These should be from $\frac{1}{8}$ to $\frac{3}{8}$ inch wide on the upper edge and from 12 to 18 inches long, depending on the weight and size of the armature to be balanced. They should be set level and parallel, and at such a distance apart that the journals of the armature shaft will rest on them.

To balance the armature, place it on the ways, when it will turn over until the heavy side is beneath. A small weight, as a piece of solder, is then temporarily fixed to the upper part of the armature, which is then given a slight motion by the

hand. It will settle in a new position, when another weight may be temporarily affixed to the armature, or a little of the other weight removed, according to the judgment of the workman. This operation should be continued until the armature shows no decided tendency to remain in any one position; the weights may then be permanently fastened in place.

The method of repairing broken leads, connections, and the like may be readily seen from the nature of the fault. In any kind of repair, the object in view should be to replace the defective part so that it will be exactly as it was before being damaged, unless, as before stated, the conditions can be improved.

MOTORS

76. Reversibility of Dynamo-Electric Machines. If, instead of forcibly revolving the armature of a dynamo and thereby generating an electric current, we supply the machine with current at the proper voltage, the armature will be revolved with sufficient force to do mechanical work. An electric machine used in this manner is called a **motor.** Combinations of dynamos and motors are extensively used in telephony.

OPERATION OF DIRECT-CURRENT MOTORS

STARTING AND REGULATING DEVICES

77. The preceding discussion regarding the selection, installation, and care of electrical machinery applies with equal force to both dynamos and motors. Each may develop faults in insulation, open circuits, short circuits, etc. and each may cause trouble by sparking. The tests and the remedies in each case are practically the same. In the operation of motors, however, there are some features requiring special mention. Auxiliary apparatus is usually necessary with motors and a brief description of some of the most commonly used *starting rheostats* and *speed controllers* will be given.

78. When motors are operated on constant-potential direct-current circuits, it is necessary to insert a resistance in series with the armature when starting the motor. In the case of a series motor, this starting resistance is also in series with the field. The resistance of a motor armature is very small, and that of a series-field is also small, so that if the machine were connected directly across the circuit while standing still, there would be an enormous rush of current, because the motor would be generating no counter electromotive force. For example, if a shunt motor of which the armature resistance is .1 ohm, were connected across a 110-volt circuit while the motor was at a standstill, the current that would flow momentarily would be $110 \div .1 = 1,100$ amperes, the amount being limited only by the resistance and self-induction of the armature. The rush of current through a series motor would not be quite so bad, as the field winding, owing both to its resistance and its inductance, would help to choke the current back.

Small motors, especially if series-wound, may be started by switching them directly on to the circuit. The ability to do this successfully depends on the style of winding, the voltage, and the load the motor is required to start. Before attempting to start a motor in this way, the manufacturers of the motor should be consulted and their advice should be followed.

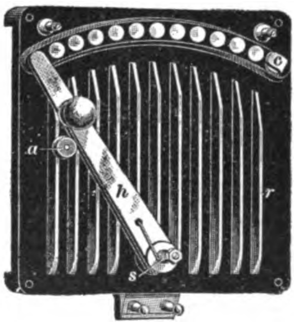


Fig. 15

79. Starting Rheostats. The **starting rheostat**, or **starting box**, as it is often called, is simply a resistance divided into a number of sections and connected to a switch arm, by means of which these sections can be cut out as the motor comes up to full speed. When the motor is running at full speed, this resistance is completely cut out, so that no energy is lost in it.

Fig. 15 shows a simple form of starting box, the resistance wire being embedded in enamel on the back of an iron plate,

while the iron ribs *r* on the front are intended to present a large radiating surface that may be cooled by the air. The handle *h* of the rheostat shown is provided with a spiral spring *s* tending to hold it against the stop *a*, which makes it impossible to leave the contact arm *h* on any of the intermediate points. On the last point, a clip *c* is placed to hold the arm of the rheostat. When the arm is in this clip, all the resistance is cut out. Starting rheostats are not designed to carry current continuously and should therefore never be used for regulating the speed of the motor. The resistance wire is made of such a size as to be capable of carrying the current for a short time only, usually 15 to 30 seconds, and if the current is left on continuously, the rheostat will be burned out.

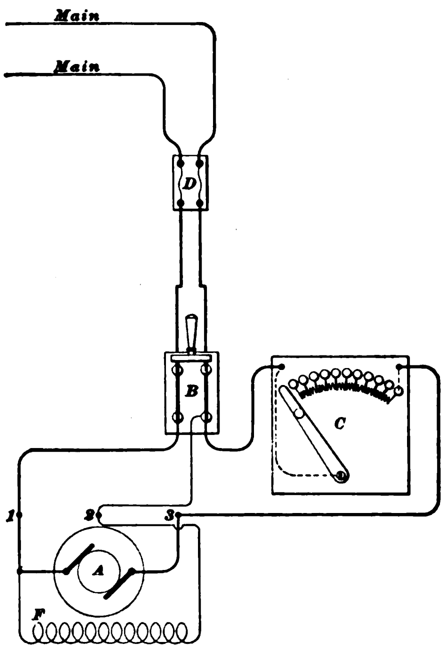


FIG. 16

Starting rheostats are made in a great variety of forms and sizes, but the object is the same in all of them, that is, to provide a resistance that may be inserted when the motor is at rest and gradually cut out as the motor comes up to speed.

SHUNT-MOTOR CONNECTIONS

80. One method of connecting a shunt motor to constant-potential mains is shown in Fig. 16. The lines leading to the motor are connected to the mains through a fuse block *D*, from which they are led to a double-pole knife switch *B*. One end of the shunt field *F* and one brush are connected to

terminal *1* of the motor; the other field terminal is connected to terminal *2*, and the other brush to terminal *3*, which is connected to one rheostat terminal. One side of the main switch connects to terminal *1*; the other side connects to terminal *2* and also through the starting rheostat *C*, to terminal *3*. As soon as the main switch is closed, current will flow through the field *F*. When the rheostat arm is moved to the first contact button, current will flow through the starting resistance and the armature *A* and the motor will start; as the handle is moved over slowly to the last point, the motor gradually attains its full speed.

81. Fig. 16 shows connections for a motor having a three-point terminal block, one point for each line wire and a point for one field terminal, the other field terminal being brought directly to a brush. Modern motors are usually provided with a separate terminal point for each field and armature lead; that is, a four-point block for a shunt motor. With such a block, the direction of current through either the field or armature can be reversed independently of the other, making it easy to reverse the direction of rotation of the armature. Where desired, such reversals are usually provided for in a controller so that a movement of the controller handle will reverse the direction of rotation.

82. Methods of Connecting.—Fig. 17 shows three methods of connecting a shunt motor. The switches are shown as single pole for the sake of clearness in the diagram. In Fig. 17 (*a*), the shunt field is excited as soon as the switches are thrown; this is the method used in Fig. 16, except there is no release magnet in Fig. 16. In Fig. 17 (*b*), the shunt field is not excited until the rheostat lever is thrown to the first button, and when the lever is moved over to its full-on position the field current must flow back through the starting resistance; this is objectionable, but as the resistance is usually low and the field current small, little harm results. On some rheostats, an auxiliary contact and path is provided, as shown by *a* and the dotted line, to lead the field current around the armature resistance when the lever is in the full-on

position. A wrong connection frequently made is shown in Fig. 17 (*c*). The shunt field, instead of being connected across the line, is connected directly across the armature terminals when the lever is on any of the contacts and hence receives only the voltage applied to the armature.

83. Automatic, No-Voltage, Release, Starting Rheostat.—In Fig. 16, the simplest type of rheostat was

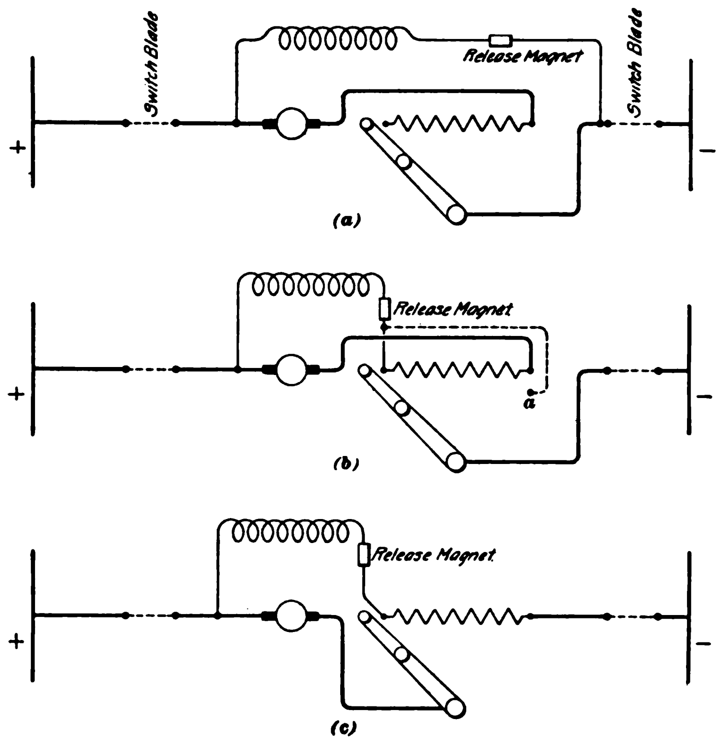


FIG. 17

shown in order to make the connections as clear as possible; but such rheostats are now used but little for the following reasons: Suppose that a motor is shut down by opening the main switch and the attendant forgets to move the rheostat arm back to the off-position. When the motor is started up again, the chances are that it will not be noticed that the rheostat

arm is at the on-position, and when the main switch is closed a rush of current that may damage the motor takes place. Again, the motor may be running and the current in the supply circuit may, for some reason, cease long enough to allow the motor to slow down or stop, and when the voltage again starts suddenly to increase, the rheostat is at the on-position, thereby allowing a large rush of current to flow through the motor. For these reasons, it is customary to arrange on almost every starting rheostat what is called an **automatic,**

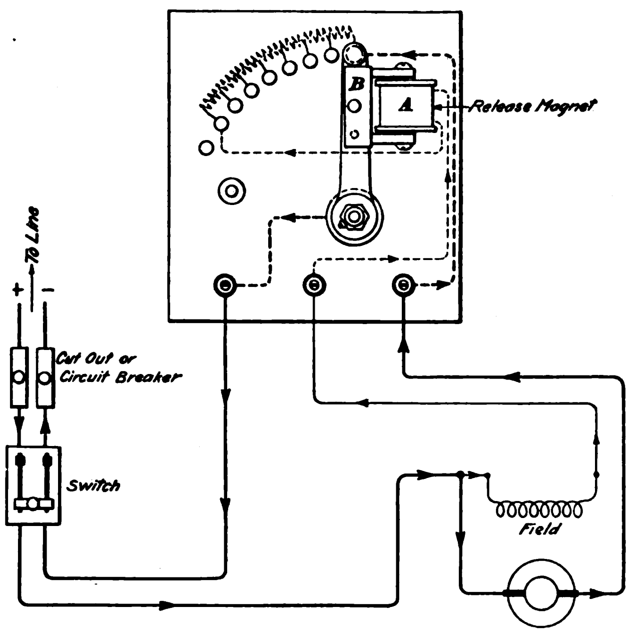


FIG. 18

no-voltage, release mechanism so that the rheostat handle will fly to the off-position whenever the power is cut off from the motor.

84. Fig. 18 shows a simple form of automatic rheostat made by the General Electric Company and its connection to a motor. The automatic feature consists of an electromagnet *A* in series with the motor field. The lever is moved

over against the action of a coiled spring, and is held at the full-on position by the attraction of magnet *A* for the armature *B*. If the current supply be interrupted, the current in coil *A* gradually decreases as the motor slows up and the pull of the magnet becomes weaker, until finally the armature *B* is released, and the arm flies back to the off-position. With such a rheostat, the proper way to stop the motor is to open the main switch and let the rheostat take care of itself. The release magnet is connected in the field circuit because it then protects the machine in case only the field circuit is broken.

The automatic release magnet, instead of being connected in series with the shunt-field circuit, is sometimes connected, with or without a resistance in series, directly across the main circuit so that the release coil is excited independently of the shunt-field current. This is nearly always the case with rheostats for series-wound motors and some manufacturers adopt this plan for all their no-voltage magnets.

85. Cutler-Hammer Rheostat.—Fig. 19 shows a Cutler-Hammer Manufacturing Company's automatic, no-voltage, release, starting rheostat with connections made according to their usual plan for shunt- and compound-wound starters, as indicated in Fig. 17 (*b*). The wrong connections shown in Fig. 17 (*c*), are made by interchanging the wires coming to the two binding posts on the rheostat marked *Line* and *Arm*. This is frequently done by careless workmen and the result is that the motor will not start until the lever has been moved over several contacts and then, if the machine starts at all, it is with a sudden jerk, and a very high speed is attained almost at once.

An advantage claimed for the connections shown in Fig. 17 (*a*) is that the field is fully excited before any current flows through the armature and that a better torque is thereby obtained when the lever is moved to the first contact than if the field magnetism must build up after the first contact is made, as is the case with the connections shown in Fig. 17 (*b*). But the time required for the magnetism of

small motors to reach a maximum is so short that the advantage claimed for the connections shown in Fig. 17 (*b*) is of little importance. With large motors, the claim is probably justifiable and the advantage of considerable importance.

On the other hand, with the method of connecting shown in Fig. 17 (*b*), it is impossible to open the field circuit, as it is always closed through the armature and the rheostat resistance. With the connections shown in Fig. 17 (*a*), the field circuit may be broken after the main switch is opened, by

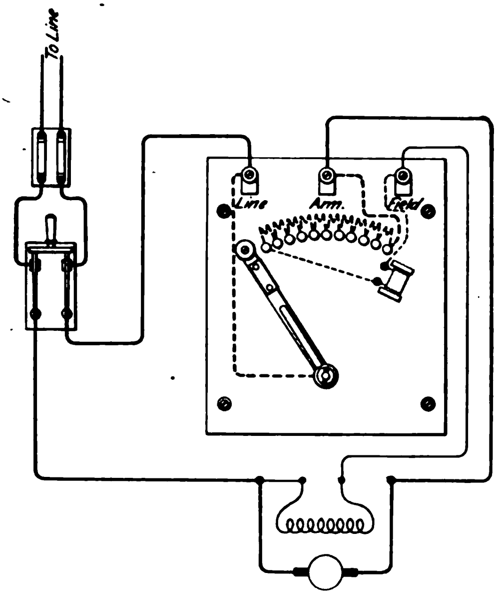
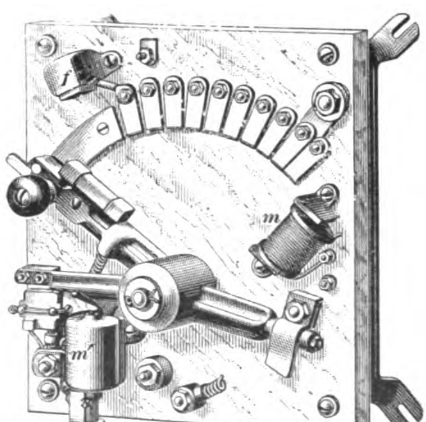


FIG. 19

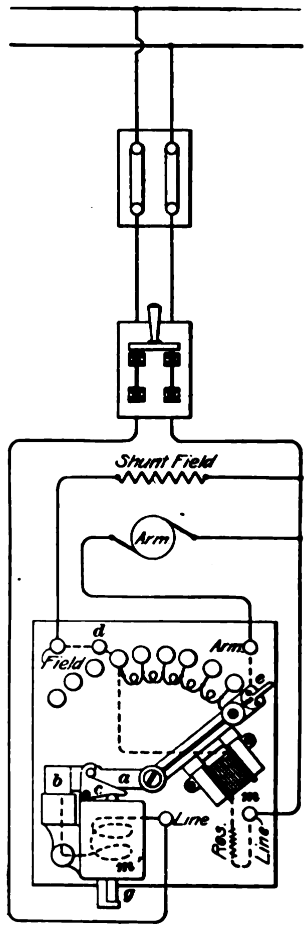
the rheostat arm opening the circuit consisting of the armature and field before the counter electromotive force, which tends to maintain the field current, ceases. On any but very small machines, it is not good practice to suddenly break a shunt-field circuit in which current is flowing because the sudden interruption of the flow of current will induce in the coil itself a voltage that may be high enough to puncture the insulation. For this reason, when the connections shown in Fig. 17 (*a*) are used on large machines, a by-pass or

high-resistance path is sometimes so arranged that it will be connected across the field terminals just before the field circuit is broken. The field discharge then passes harmlessly through the by-pass, which is finally opened.

86. Automatic No-Voltage and Overload-Release Starting Rheostat. Fig. 20 (*a*) shows the front of a Ward Leonard Electric Company's SKE type motor starter and Fig. 20 (*b*) shows the diagram of connections. An automatic, no-voltage, release magnet *m* is connected with a resistance in series across the circuit independent of the shunt field; and an overload-release magnet *m′* is connected in



(*a*)



(*b*)

FIG. 20

series with one line so that all current to the motor must flow through magnet *m′*, blades *b*, arm *a*, the rheostat handle, and the starting resistance, to the armature as well as to the shunt field and the no-voltage release magnet. If

the motor is so overloaded that the current required exceeds a predetermined amount, the core *g* of magnet *m'* is drawn up, turning catch *c* on a pivot so that arm *a*, which is held closed by the catch against the action of a spring, flies upwards, opening the circuit, thus demagnetizing magnet *m* and releasing the rheostat handle, which returns to the off-position. The arrangement on this rheostat is such that arm *a* cannot be closed until the rheostat handle has returned to the off-position. The overload feature just described is properly called a circuit-breaker. On the end of the rheostat handle is a small pivoted tongue *e* held in a central position by a spring. This arrangement, known as a *flipper switch*, catches an auxiliary button or projection *d* when the arm is returning to the off-position and maintains contact with it until the arm has left the first resistance contact, after which the flipper snaps back into its normal position, quickly breaking the arc and thus protecting the main contacts from being burned. On sizes above 10 horsepower, a magnet *f*, shown only in Fig. 20 (*a*), which is a 15-horsepower size, is also arranged to blow out the arc.

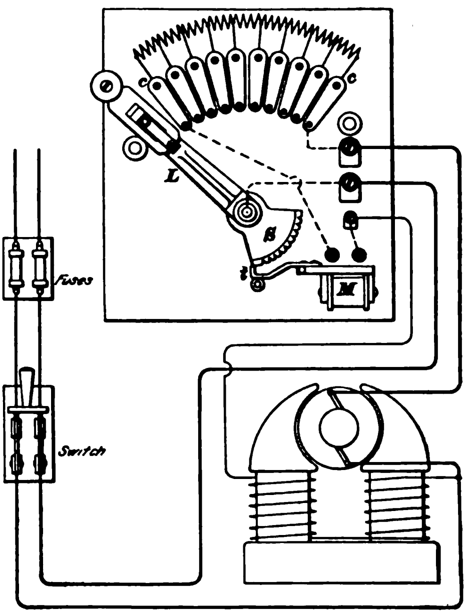


FIG. 21

In another type of overload release rheostat much used, the action of the overload-release magnet closes a short-circuit around the no-voltage magnet, thus releasing the rheostat arm, which flies back to the off-position.

87. Speed Regulating Rheostats.—**Speed regulating rheostats,** often called **speed regulators,** are very similar in construction, in appearance, and in connections to starting rheostats except that regulators, owing to their greatly increased carrying capacity, are much the larger. The chief difference between the two, however, is that while a starting rheostat has resistance so proportioned as to carry the starting current required by the motor armature for only a few seconds, usually not over 15, a speed regulator has resistance designed to carry the armature current continuously. The starting-rheostat lever should, therefore, never be held longer than 2 or 3 seconds on any step except the last, on which the resistance is all cut out. The speed-regulator lever is usually arranged to be held automatically on any desired step. Fig. 21 shows the connections of an

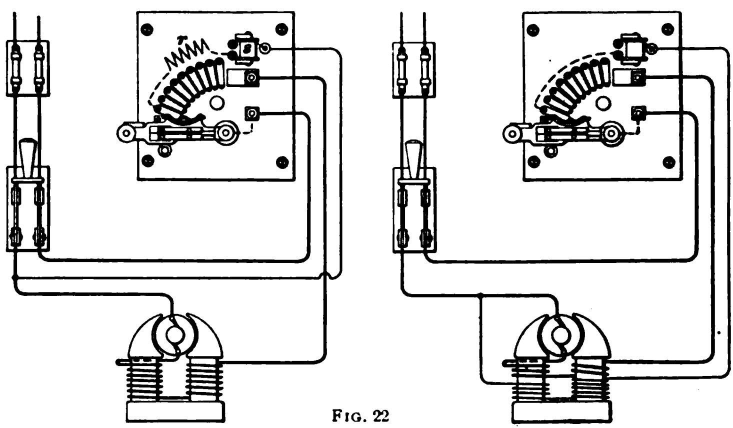


FIG. 22

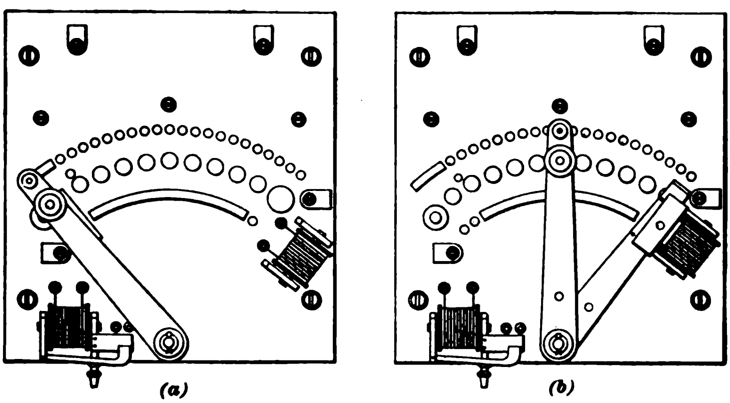
automatic speed regulator. The segment S is rigidly fastened to the lever L and turns with it. A pawl or catch t is held in the notches in S by the action of the magnet M. The notches are so distributed that each will hold the lever squarely over one of the contact segments c, c. If the voltage of the circuit fails or if the switch is opened, the magnet m releases the pawl t and the lever flies back to its initial position. In this regulator, the contact segments c, c are renewable and may be easily replaced when worn or burned.

SERIES- AND COMPOUND-MOTOR CONNECTIONS

88. Connections for shunt motors have been discussed first because they are the most complicated and the most common. If these are fully understood, the methods of connecting the other field windings will then be easily derived. Fig. 22 shows simple diagrams of connections for series- and compound-wound motor starters with automatic underload release. The release spools *s* of a series-motor starter is usually connected directly across the circuit with a resistance *r* in series unless the voltage of the circuit is very low, in which case the resistance is omitted.

Since its field helps to choke back the starting current, a series motor does not require as large a starting resistance as a shunt motor.

89. Compound Starting and Regulating Rheostat. In Fig. 23 is shown a type of rheostat designed for starting



(a) (b)

Fig. 23

a motor and then for regulating its speed by means of a variable resistance inserted in the shunt field of the motor. There are two arms, the off-positions of which are shown by Fig. 23 (*a*). The large round contacts connect to the resistance for the armature circuit and are for starting duty only. The smaller round contact connects to the field resistance used for regulating the

speed. The solid metal sector below the larger contacts short-circuits the field-regulating resistance during the operation of starting.

When all the armature resistance is cut out by moving the arms to the extreme right-hand limit of their motion, the short circuit is removed from the field-regulating resistance by means of the small contact at the right-hand end of the sector; the armature lever is held by the retaining magnet, as shown in Fig. 23 (*b*), and the speed can be regulated by moving the field lever to the left, thus cutting in resistance in the shunt-field circuit. The armature lever is provided with a spring; the field lever is not, and thus it can be left in any position. In case of no-voltage, the retaining magnet releases the armature lever, which comes in contact with the field lever, and both levers are forced to the off-position. In case of an excessive load, the overload magnet placed near the left-hand lower corner of the box will operate the retaining magnet, by short-circuiting it, and release the armature lever.

INSTALLING A DIRECT-CURRENT MOTOR

90. When installing a motor in an isolated place where a voltmeter is not available, it is well to permanently connect an incandescent lamp across the circuit near the motor so as to supply a ready means of ascertaining whether power is on the line at any time. By using a key socket, or receptacle, the lamp may be switched off when not needed.

Before attempting to start the motor see if there is power on the line and then close the main switch; this may or may not allow a current to flow through the motor fields, according to the kind of winding and the method of connecting. Move the lever of the starting rheostat quickly and squarely to the first contact segment and let it stay there for 2 or 3 seconds. The motor should start at once and begin to increase in speed. Move the lever from segment to segment, stopping on each but 2 or 3 seconds, until the full-on, or short-circuit, position is reached, where the lever should be firmly held by the retaining magnet. During this process, the motor speed

should have gradually increased to full speed, the total time required to accelerate to full speed being usually about 15 seconds. Do not hold the lever longer than indicated on any contact, unless the starting resistance be intended also for speed control. If the motor does not start when the lever is on the first contact move quickly to the second. If still no start is made move to the third; if the machine then fails to start, immediately open the main-line switch and look for the cause of the failure.

91. The failure may result from any one or more of several causes, namely:

1. *Wrong connections* of the field coils among themselves or with other parts of the circuit. Make sure that the shunt field obtains the full voltage when the lever is on the first step, and that the poles are magnetized.

2. An *overload* on the motor; when a motor is first installed, the current required to start its load, as well as the running current after obtaining full speed, should be ascertained. An ordinary motor intended for continuous service should not be expected to start a load requiring more than double its rating, in amperes. This rating is usually stamped on the name plate. Motors intended for intermittent service, such as railway and hoisting work, are designed to start with almost any load up to what will actually stall the armature.

3. An *open circuit* due, possibly, to a defective switch, a broken wire or poor connection in the starting box, or the brush not making good contact with the commutator, or an open circuit within the motor itself.

4. A *short circuit* will nearly always make its presence and possibly its location known. Among the more common sources of short-circuiting are: short-circuited armature coils; short-circuited commutator; short-circuited field coils; brushes in the wrong position. If the armature coils or commutator are short-circuited, the machine may start and turn over part way and stop again. With a series-field coil short-circuited, the armature will start only under a heavy current, with accompanying sparking, and will acquire a high rate of speed. A

wrong position of the brushes will usually be indicated by violent sparking. The correct position may be found by trial if it is not marked on the frame.

REVERSING THE DIRECTION OF ROTATION

92. If the current in either the field or the armature of a motor is reversed, the direction of rotation will be reversed; but if the current in both the field and armature be reversed, the direction of motion will remain unchanged. A series motor will, therefore, run in the same direction, whatever the direction of the current through the machine as a whole. Reversing the line connections to the motor terminals simply reverses the current through both armature and field and does not change the direction of rotation. In order to reverse a series motor, either the armature terminals must be interchanged, so as to reverse the current through the armature only, or the field terminals must be interchanged so as to reverse the current through the field only.

POWER EQUIPMENT

(PART 2)

DYNAMO-ELECTRIC MACHINES

ALTERNATING-CURRENT MOTORS

DEFINITIONS

1. Motors designed for use in connection with alternating currents may as a rule be divided into two classes, *synchronous* and *induction*. Both kinds are in common use, and by far the larger part of all the motors operated in connection with alternating current belong to one of these classes. There are a few other motors used to some extent, but their number is insignificant compared with those of these two classes.

2. Single-Phase and Polyphase Currents.—Two alternating currents are said to be *in phase* when they pass through corresponding values in the same direction in their cycles at the same instant. To be, or at least to continue, in phase, the two currents must have the same frequency. A single alternating current flowing in a system of conductors is called a **single-phase current.** Two alternating currents in the same system, differing from each other in phase by one-fourth a cycle, or 90°, make a **two-phase,** or **quarter-phase, system.** Three alternating currents in the same system, differing in phase from one another by one-third a cycle, or 120°, make a **three-phase system.** Alternating-current

systems through which flow more than a single alternating current, are called **polyphase systems.** Coils possessing inductance are called **choke, impedance,** or **reactance coils.**

3. Power Factor.—If a circuit possesses *inductance*, the current lags behind the electromotive force; and if it possesses *capacity*, the current leads the electromotive force. When the circuit possesses only a non-inductive resistance, the current and electromotive force are in phase. Consequently, the product of the reading of an ammeter and the reading of a voltmeter in an alternating-current circuit gives the true power, in watts, expended in the circuit only when the circuit consists of a non-inductive resistance or occasionally when the inductance balances the capacity, leaving as before only the non-inductive resistance to be considered. In all other cases, the true power, in watts, is obtained by multiplying the product of the volts and amperes by a quantity that may be different for every circuit or even for the same circuit under different conditions. This quantity is called the **power factor** of the circuit or system.

The product of a voltmeter reading and an ammeter reading taken simultaneously on the same circuit is called the **apparent watts.** The **true watts** are given by the reading of a wattmeter, which, in its action, allows for the difference in phase between the electromotive force and current. The power factor of a system may then be defined as that quantity by which the apparent watts expended in the system must be multiplied to give the true watts. The power factor is equivalent to the cosine of the phase angle between the current and electromotive force. The power of a circuit containing only incandescent lamps, which are non-inductive resistances, is very nearly 1; that is, the true watts are nearly equivalent to the apparent watts.

4. Transformers.—An ordinary **transformer** is essentially an induction coil having usually a closed magnetic circuit of iron, a primary coil, and a secondary coil. The primary coil is usually wound with many turns of fine wire and the

secondary with fewer turns of larger wire. The coils and core are usually enclosed in an iron case. Transformers are used on alternating-current circuits to transform a small current at a high voltage to a larger current at a lower voltage, or vice versa.

An **autotransformer** is a transformer having but one winding, which serves both for the primary and secondary coils. Fig. 1 shows the general arrangement. On the laminated iron core A are wound two coils t and t' which are connected in series so that they practically form one coil. The primary line wires are connected to the terminals a and b and the secondary line wires to c and a. The ratio of the secondary potential E_s to the primary potential E_p depends on the ratio of the number of turns of the larger wire t' to the total number of turns between the terminals a and b. For example, if the larger wire t' has one-third the total number of turns, the voltage E_s will be about one-third the line voltage and the current taken from the secondary will be about three times that drawn from the line wires. The secondary terminals may be connected to points anywhere along the coil.

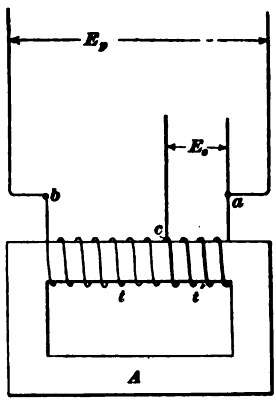


FIG. 1

SYNCHRONOUS MOTORS

5. Synchronous motors are made to operate either on single-phase or polyphase systems, and are so called because they always run in synchronism with, or at the same frequency as, the alternator driving them. In construction, they are almost identical with the corresponding alternator, and always consist of the two essential parts—field and armature—either of which may revolve. The field of such motors must be excited from a separate continuous-current machine in the same way as an alternator.

Synchronous motors behave differently in some respects from direct-current machines. If the field of a direct-current motor is weakened, the motor will speed up. If the field strength of a synchronous motor is changed, the speed cannot change, because the motor must keep in step with the alternator. Such a motor adjusts itself to changes of load and field strength by the changing of the phase difference between the current and electromotive force. Synchronous motors are used mostly for work where the motor is not started and stopped frequently, and where it is not started under load. They are used mostly in the larger sizes. For ordinary work, involving frequent starting and stopping under load, induction motors are preferable.

6. **Single-Phase Synchronous Motors.**—If a single-phase alternator is connected to a similar machine, the latter will not start up and run as a motor, because the current is rapidly reversing in its armature, thus tending to make it turn first in one direction and then in the other. The consequence is that the armature does not get started from rest. If, however, the second machine is first run up to a speed such that the frequency of its alternations is the same as that of the alternator, and then connected in circuit, the impulses of current will tend to keep it rotating and the machine will continue running as a motor. The motor must be run up to synchronism by means of some outside source of power, usually by means of a small self-starting motor. After the large motor has been brought up to synchronism, the small starting motor is disconnected by means of a clutch, and is then shut down. Because **single-phase synchronous motors** will not start of their own accord they are seldom used.

7. **Polyphase Synchronous Motors.**—Synchronous motors operated from two- and three-phase alternating-current circuits are called **polyphase synchronous motors.** They will start from rest and run up to synchronism when their armature windings are supplied with current, although in doing so they take a large current from the line; and if the motor is a large one, it is better to bring it up to speed by means

of some outside source of power, such as an auxiliary motor. After the machine has come up to synchronism, its fields are excited by an exciter in the same way as a single-phase motor or alternator.

8. Speed and Direction of Rotation.—The speed at which a synchronous motor will run when connected to an alternator of frequency n is

$$s=\frac{2\,n}{p}$$

in which s = speed, in revolutions per second;
p = number of poles on motor.

For example, if a ten-pole motor is run from a 25-cycle alternator, the speed of the motor will be

$$s=\frac{2\times 25}{10}=5 \text{ revolutions per second}$$

or 300 revolutions per minute. The speed of an induction motor when not loaded is found in the same manner.

A synchronous motor will run in either direction, depending on the direction it is revolved when started up by its auxiliary motor. If, however, it is started by simply allowing current to flow through the armature, its direction of rotation will depend on the way in which the armature terminals are connected to the line. Interchanging any two of the leads of a three-phase motor will reverse the direction of rotation, while interchanging the two wires of either phase of a two-phase motor will accomplish the same result.

INDUCTION MOTORS

9. In a great many cases it is necessary to have an alternating-current motor that will not only start up of its own accord, but one that will start with a strong torque. This is a necessity in all cases where the motor must start up under load. It is also often necessary for the motor to be started and stopped frequently, and in general to be used in the same way as a direct-current motor. These requirements are fulfilled by **induction motors.**

10. Essential Parts of Induction Motors.—Induction motors are usually made for operation on two- or three-phase circuits, although they are sometimes operated on single-phase circuits. They always consist of two essential parts, namely, the *primary*, or field, to which the line is connected, and the *secondary*, or armature, in which currents are induced by the action of the primary. Either of these parts may be the revolving member, but the usual arrangement is for the field to be stationary and the armature revolving. In a synchronous or a direct-current motor, the current is led into the armature from the line, and these currents, reacting on a fixed field, provided by the stationary field magnet, produce the motion. In the induction motor, however, two or more currents differing in phase are led into the field, thus producing a magnetic field that is constantly changing and inducing currents in the armature coils, which form closed circuits. These induced currents produce a field of their own, which react on the motor field and produce the motion of the armature. It is on account of this action that these machines are called induction motors.

11. Reversing Direction of Rotation.—In order to reverse the direction of rotation of an induction motor, it is necessary to reverse the rotation of the revolving magnetism set up by the field windings. In a two-phase motor, this can be done by reversing the current in either of the phases; that is, by interchanging the connections of the wires leading from one pair of supply mains to their terminals on the motor. A three-phase motor can be reversed by interchanging the connections of any two of the line wires with the motor terminals.

12. Slip.—If the armature is held from turning in a revolving field, the coils on the armature will act like the secondary of an ordinary transformer, and heavy currents will be set up in them. However, as the armature comes up to speed, the relative motion between the revolving field and armature becomes less, and the induced electromotive forces and currents become smaller, because the secondary turns do not cut as many lines of force per second as before. If

the armature is running exactly in synchronism with the field, there will be no cutting of lines whatever, no currents will be induced, and the motor will exert no torque. Therefore, in order to have any induced currents, there must be a difference in speed between the armature and the revolving field, and the greater the current and consequent torque or effort, the greater must be this difference. When the load is very light, the motor runs very nearly in synchronism, but the speed drops off as the load is increased. This difference between the speed of the armature and that of the field for any given load is called the **slip.**

13. The slip in well-designed motors does not need to be very great, because the armatures are made of such low resistance that a small secondary electromotive force causes the necessary current to flow. In well-designed machines, it varies from 2 to 5 per cent. of the synchronous speed, depending on the size. A 20-horsepower motor at full load might drop about 5 per cent. in speed, while a 75-horsepower motor might fall off about $2\frac{1}{2}$ per cent. For example, if an eight-pole motor, which has four pair of poles, is supplied with current at a frequency of 60, its field will make $60 \div 4 = 15$ revolutions per second, or 900 revolutions per minute, and its no-load speed will be very nearly 900. At full load, the slip might be 5 per cent., so that the speed will then be 855 revolutions per minute. This shows that as far as speed regulation goes, induction motors are fully equal to direct-current machines.

14. Calculating the Slip.—If S' represents the speed of the armature and S the speed of the revolving field in revolutions per second, then the

$$\text{slip} = S - S' \qquad (1)$$

Expressed as a percentage of the speed that the armature will run at if it is in synchronism with the field, the percentage slip x is

$$x = \frac{(S-S')\,100}{S} \qquad (2)$$

Both S and S' must be expressed in revolutions per second or revolutions per minute

EXAMPLE.—If the armature of an induction motor makes 1,200 revolutions a minute and the percentage slip is 10, what is the speed of the revolving field?

SOLUTION.—Solving formula **2**, for S', gives $\frac{S\ x}{100} = S - S'$, or $S' = S - \frac{S\ x}{100}$. Substituting the known values gives $S' = 1{,}200 - \frac{1{,}200 \times 10}{100} = 1{,}200 - 120$ $= 1{,}080$ rev. per min. Ans.

15. Speed Regulation of Induction Motors.—The induction motor tends to run nearly in synchronism with the alternator that supplies it with current. Its speed can never rise above that of synchronism; in fact, it cannot quite reach synchronism, because it always takes some power to make up for the friction losses, etc., even if the motor is unloaded. With the exception of the slight variations in speed, due to the changes in load and corresponding change in the slip, the speed of the motor remains practically constant as long as the speed of the alternator and the voltage on the line remain constant. Generally speaking, the induction motor is not as well adapted for variable speed as the direct-current motor, although its speed can be varied through a considerable range by variable resistances connected through slip rings with each winding on the armature.

POLYPHASE INDUCTION MOTORS

16. A **polyphase induction motor** may be started by connecting its field directly to the line. But as this allows a large rush of current, which may be sufficient to disturb other parts of the system, this method of starting is objectionable and not practicable with any but small motors. In order to start large motors smoothly, and thus avoid a rush of current, either the voltage applied to the primary may be reduced by inserting a resistance or by the use of an autotransformer; or a resistance may be inserted in the secondary at starting, and cut out when the motor comes up to speed.

An induction motor, if overloaded excessively, will stop and will soon overheat unless the current is cut off. In order to protect these motors, either fuses or circuit-breakers may be

used, though sometimes they are installed without any protective device. The fact that the motor stops if loaded excessively is often depended on to serve as an indication of overload, but this method cannot be recommended, and it is better to have some form of protective device.

17. Starting Compensator, or Autotransformer. Where a motor is provided with a so-called *squirrel-cage*, or *short-circuited, winding*, it is generally started by cutting down the voltage applied to the primary. This is usually done by means of an autotransformer inserted between the line and the motor field, the transformer being provided with a double-throw

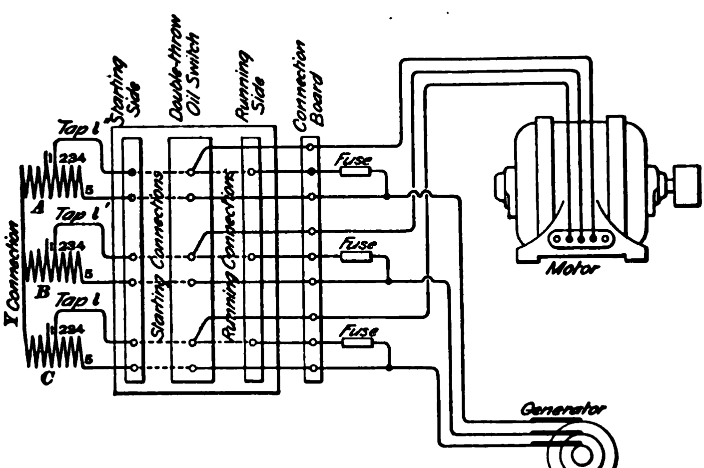


FIG. 2

switch, so that it can be cut out when the motor has come up to speed.

In Fig. 2 are shown the connections for starting a three-phase induction motor by means of an autotransformer. Each coil *A*, *B*, and *C* of the autotransformer is provided with a number of taps *1*, *2*, *3*, and *4* in order that the starting current can be varied to suit the conditions under which the motor is used. When the switch is thrown to the left, as indicated by the dotted lines in the *starting connections*, the coils *A*, *B*, and *C* are connected in circuit with the supply generator or mains.

The motor windings are, however, connected only across that portion of each coil that lies between the points *1* and *5*; consequently, the voltage applied to the motor is decreased and the current is correspondingly increased. A simple arrangement is provided so that leads *l*, *l'*, and *l''* can be connected to any of the taps *1*, *2*, *3*, or *4*, as desired. If connected to taps *4*, the maximum starting effort is obtained with a correspondingly large current taken from the line. When the motor is installed, the proper tap to use for good starting is determined by trial, and the tap connection is then securely made and probably will not have to be altered. The two-phase starter has two coils but its principle of operation is the same.

18. The motor is started by throwing the switch from the off-position to the starting position. After the motor has come up to nearly full speed, the switch is thrown over to the right or running position, as indicated by the dotted lines in the *running connections*, thus cutting the autotransformers out of circuit. When starting motors with such devices, enough time should be allowed after the switch is placed in the starting position for the motor to come up to nearly full speed before turning the switch to the running position, otherwise the fuses in the supply leads are very apt to be blown.

19. Starting Without Compensator.—In some cases, a low starting voltage can be obtained without the use of a compensator. For example, the step-down transformers that supply the motor can have taps brought out from the middle point of their windings and connected to a double-throw switch, so that in one position of the switch the motor gets only one-half the normal voltage, while for the running position of the switch it is connected across the secondaries in the usual manner and gets the full voltage.

Some induction motors are started with a resistance mounted in the armature. When the machine reaches full speed, this resistance is cut out by pushing in a handle projecting from one end of the hollow armature shaft. This eliminates the use of collector rings

SINGLE-PHASE INDUCTION MOTORS

20. Splitting the Phase.—A motor constructed on the same lines as an induction motor, but provided with only a single winding on the field, instead of two or more sets of windings, as in the polyphase induction motors will not start up of its own accord when it is connected to single-phase mains. If, however, it is in any way given a start, it will gradually come up to speed in whichever direction it is started, provided that no load is applied. The motor will exert very little torque, but it will gradually increase in speed until it attains a speed nearly in synchronism with the generator. As soon as the motor is running in synchronism with the current, the load may be applied and the motor will behave in the same way as one operated on a polyphase system.

In order to make a single-phase motor start from rest and give a good starting torque, it is necessary to provide a rotating field at starting. This can be done by using regular two-phase or three-phase windings on the motor and supplying these windings with displaced electromotive forces obtained by **splitting the phase,** as it is called. Many methods for phase splitting are in use.

21. Starting Single-Phase Induction Motors. In Fig. 3, the motor is provided with a two-phase winding. A non-inductive resistance R is connected in series with one winding A, and an inductance coil L is connected in series with the other B. These two windings are connected in parallel across the same line wire. The current in one winding B will lag behind that in the other winding A, so that if the resistance and inductance are correctly proportioned the currents can be made

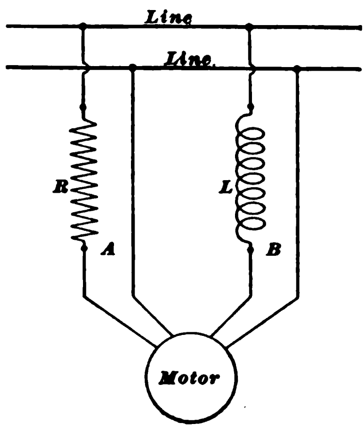


FIG. 3

to differ enough in phase to produce an imperfect form of rotating field sufficient to start the motor. The windings are frequently so designed that the necessary phase displacement is caused by the windings themselves, and outside resistance and inductance are rendered unnecessary. In some cases, one of the windings is a main, or working, winding; the other is then used only at starting, being cut out by being open-circuited by means of a switch after the motor has attained its speed.

22. In Fig. 4 is shown another scheme for starting a motor on single-phase mains. Two of the terminals are connected

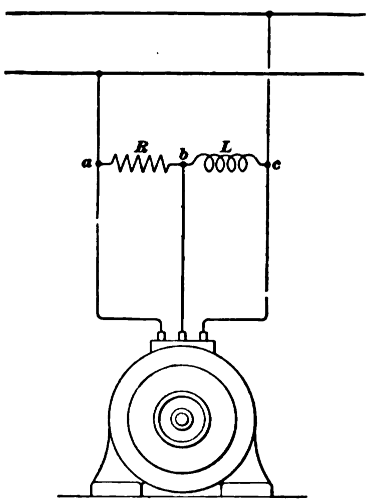


FIG. 4

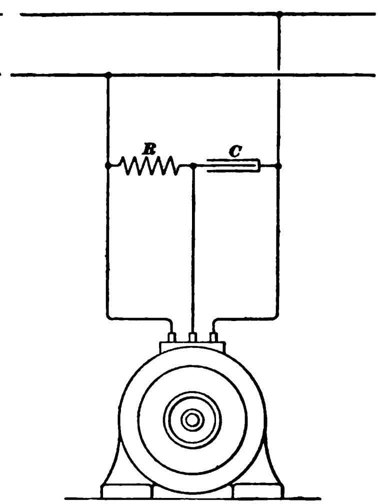


FIG. 5

to the mains, and the third terminal is connected to a point *b* between the resistance coil *R* and the inductance coil *L*. The electromotive force between the points *a* and *b* differs in phase from that between the points *b* and *c*, so that the different windings of the motor are supplied with displaced electromotive forces suitable for starting. A switch can easily be arranged to disconnect the resistance *R* and inductance *L* after the motor has come up to speed thus running it on the two outside lines only.

In Fig. 5 is shown a starting arrangement similar to that shown in Fig. 4, except that a condenser C is used instead of the inductance L. Sometimes, where this combination is used, the resistance coil R and the condenser C are not cut out after the motor has attained speed, because the condenser C counteracts the self-induction of the motor and thus raises its power factor to such an extent that the small amount of loss in the resistance coil R is more than made up.

SERIES MOTOR ON ALTERNATING CURRENT

23. If a motor constructed in every way like a series-wound direct-current machine is provided with laminated fields and supplied with current from alternating-current mains, it will start with a good torque and run up to speed under load, thus making a single-phase alternating-current motor. As the field is in series with the armature, the currents in the field and in the armature reverse at the same instant. If the currents in both field and armature of direct-current motors are reversed, the direction of rotation remains unchanged. Series-wound motors with laminated fields have been used to a limited extent with alternating current, but so far without success except, perhaps, in motors of small size. The chief trouble has been to design motors of considerable output that will operate without bad sparking at the commutator.

REPULSION MOTOR

24. In Fig. 6 is shown the principle of a type of single-phase alternating-current motor known as a **repulsion motor.** The laminated field A is excited by single-phase alternating-current. The armature C is provided with an ordinary direct-current winding connected to a commutator; d and e are thick brushes with their center line at an angle of about 45° with the center line of the poles.

If the brushes d and e are not in contact with the commutator when the field is excited, opposing electromotive forces will be induced in the two sides of the ring-wound armature,

like in a direct-current armature; therefore, no current will be set up in the windings and no turning effort will be exerted so that the armature will not start. However, a varying torque will be exerted on the coils located between the coils *h* and *g*, the maximum occurring in those coils situated about half way between the extremes. If, therefore, two thick brushes *d* and *e* are arranged so as to short-circuit a number of the coils lying in this region, a repulsive force will be exerted on the coils so short-circuited and the armature will revolve. The short-circuited coils are shown by heavy lines. Only those coils that are short-circuited by the brush are effective in producing rotation, so that comparatively few of the armature coils are utilized. More coils can be utilized and the repulsive effect made stronger by connecting the brushes together, as shown by the heavy dotted connection *f*.

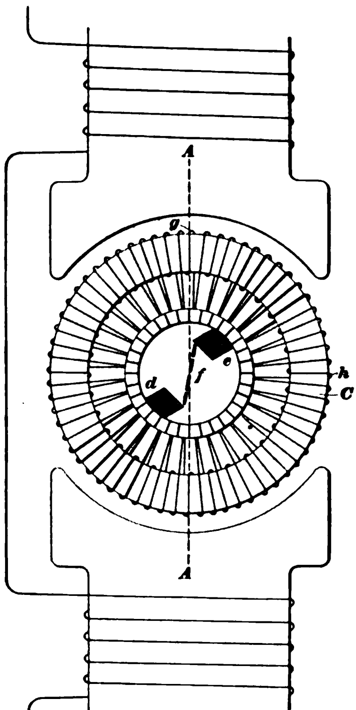


FIG. 6

When the motor has attained full speed, the commutator is short-circuited by means of a ring that automatically connects all the segments together and at the same time the brushes are lifted from the commutator, thus preventing brush friction and wear except during the time that the commutator is actually in use. It is impracticable and unnecessary to describe more fully the theory or operation of dynamos or motors.

COMBINATIONS OF DYNAMOS AND MOTORS

MOTOR GENERATORS

25. The term **motor generator,** or **motor-dynamo,** is used to designate the combination of a motor and a dynamo mounted on one base. The shafts of the two machines are rigidly coupled together, but the armature windings are distinct on each shaft and each armature has its own field. The motor is designed to be operated at any required voltage from a power or light circuit, and is started and regulated like any similar but detached motor. The dynamo is operated like any similar dynamo that is driven in any other manner. The voltage of the direct-current dynamo part of the machine may be regulated by adjusting the strength of either the dynamo or motor-field current by means of an adjustable resistance in either field circuit. A rheostat in the field circuit of the dynamo is the more common method, however. The motor may be any kind of direct- or alternating-current motor, and the dynamo may be designed to furnish direct or alternating current at almost any desirable voltage. For charging storage batteries motor generators are usually shunt-wound direct-current machines. Later types of direct-current motor generators have the generator fields excited from the direct-current street mains that supply the motor with current; this increases the efficiency.

26. The motor of a motor-generator set, if supplied with current from alternating-current mains, may be a synchronous or an induction motor. The field of a synchronous motor must be separately excited with direct current and, unless provided with some special arrangement for the purpose, the motor will not start itself. As the motor parts of motor generators, dynamotors, and rotary converters are started in practically the same manner as similar motors, the explanations for starting simple motors will also apply to these other machines.

So many varieties of satisfactory alternating-current motor generators are now on the market that no general description

that will apply to all can be given. All reliable manufacturing companies will give all the necessary directions for connecting and operating the machine of their make that is best adapted to the purpose if the voltage, the kind of circuit (whether a single-, two-, or three-phase circuit), the normal load that the motor will have to carry, and the purpose for which the motor is to be used are sent to them by a prospective purchaser.

27. There are several firms manufacturing motor generators especially for telephone exchanges and telegraph offices, in which the motor and generator are twin sets mounted on a

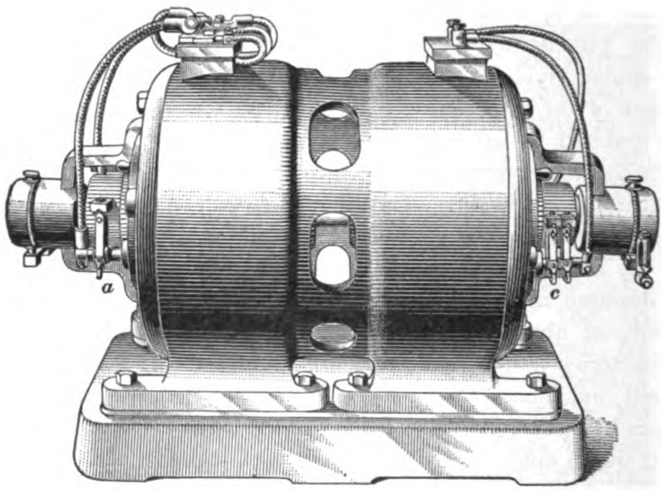


Fig. 7

common base and directly connected by means of a flexible insulating coupling keyed to the shaft. The machines are also insulated from the base, thus preventing any electrical connection between them. The bearings of the machine should be supported in such a manner as to leave the space about the commutator open and easy to get at for inspection and cleaning.

The general appearance of a motor generator, made by the Holtzer-Cabot Electric Company and others, and extensively used by telephone companies, is shown in Fig. 7. The two armature cores are carried by one long shaft supported by the

outer bearings only, no intermediate bearing being used. The principal advantage of this form of construction is its compactness. At *a* is shown the direct-current motor commutator and at *c* the direct-current dynamo commutator. The two sets of field coils and the two armatures are enclosed by a mild-steel casing that forms the yoke of the fields. The holes in the casing affords sufficient ventilation to prevent the armatures and fields from becoming overheated.

DYNAMOTORS

28. A **dynamotor** is a machine for transforming current from one voltage to another. It may be used to change from a direct current at one voltage to a direct current at another voltage, or from direct current to alternating current or vice versa. It has one magnetic field and usually only one armature, which, however, contains two windings, one winding being connected to a commutator on one side of the armature and the other winding to a commutator on the other side. Sometimes, however, there are two armatures. A dynamotor differs from a rotary converter in having two distinct armature windings.

On account of the equalizing action of the motor-armature and dynamo-armature windings, no shifting of the brushes of a dynamotor is required with a change of load. These machines are more efficient than motor generators, as there is but one field winding to consume energy; but they cannot be compound wound to insure a steady voltage at the dynamo side, as the effect of such compounding would be to correspondingly alter the motor speed.

For the same reason, it is not possible to regulate the voltage on the dynamo side of dynamotors by regulating the current in the field coils, as any change in the strength of the field will change the speed of the motor. The only way to regulate the voltage of a dynamotor is to insert resistance in series with the main supply circuit, which is very wasteful. Where voltage regulation is desirable, motor generators should be used.

ROTARY CONVERTERS

29. It is often necessary to change direct current to alternating, and vice versa; for this purpose, **rotary converters** are generally used in large power plants and frequently in telephone exchanges and telegraph offices. A rotary converter has one armature winding, one field frame, one commutator, and one set of slip rings. It is frequently called a *synchronous converter*.

A rather old type of rotary converter is illustrated in Fig. 8, as it shows the various parts better than the more modern

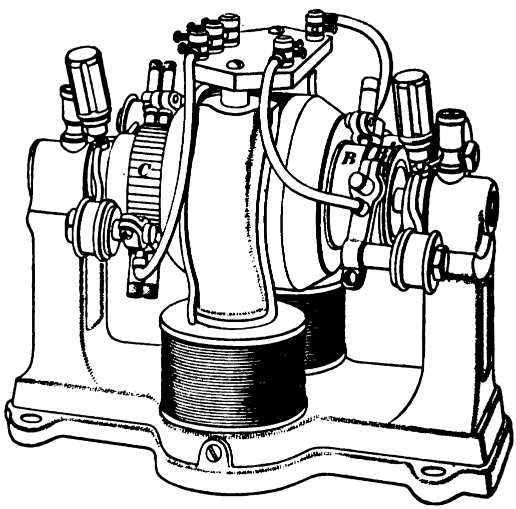


FIG. 8

enclosed machine. At the left-hand end of the armature shaft, associated with the motor side of the machine, is placed the commutator C, to the brushes of which are led the wires from the lighting or power mains, the current from which is to operate the machine. On the other end of the armature shaft are mounted two separate collecting rings B and B' for the generator windings of the machine, from which is taken an alternating current. By connecting the collecting rings to an alternating-current circuit, the alternating-current side may be used as a motor and a direct current may be taken from the

commutator, now the dynamo side of the machine. Rotary converters are manufactured by several dynamo builders and may be wound for any standard voltage on the motor side.

30. Rotary converters must have their fields excited from the direct-current side of the machine. Some manufacturers arrange their rotary converters so that they are started by connecting a part of the whole field coil temporarily in series with the motor side of the armature. A rotary converter, run from alternating-current mains, operates as a synchronous motor and hence runs at a constant speed. Unless overloaded so much as to put it out of phase with the alternator and thus cause it to stop, the speed of a rotary converter will not vary much, no matter what load may be taken from the direct-current side, provided that the speed of the alternator that supplies the current is maintained a' a constant value.

31. Starting Rotary Converters.—Converters are started in the same manner as motors; that is, the motor side of the machine is connected to the circuit and operated precisely like the corresponding kind of motor. For instance, a rotary converter supplied with direct current is started with a resistance in series with the motor armature. The resistance of the armature is so small that if the machine is connected directly across the supply circuit while standing still, there will be an enormous rush of current.

32. Voltage Regulation of Rotary Converters. When the motor side of a rotary converter is supplied with alternating current, it operates as a synchronous motor and the ratio of the alternating voltage to that on the direct-current side is a fixed quantity. For a three-phase rotary converter, the voltage on the alternating-current side is

$$E = .612\ V \qquad (1)$$

in which E = voltage between any two wires of alternating-current circuit;

V = direct-current voltage.

For example, suppose that it is desired to transform alternating current at 2,000 volts to direct current at 500 volts,

using a three-phase rotary converter. The alternating current must be supplied to the rotary converter by the transformer at a pressure of

$$E = .612\ V = .612 \times 500 = 306 \text{ volts}$$

The alternating current will, therefore, be first sent through static transformers wound so as to reduce the pressure from 2,000 to 306 volts, and the secondary coils of these transformers will be connected to the alternating-current side of the converter. For a single-phase or two-phase rotary converter the voltage on the alternating-current side is

$$E = .707\ V \qquad (2)$$

in which E = voltage between two wires of single-phase circuit or between any two wires constituting one phase of a two-phase circuit;
V = direct-current voltage.

EXAMPLE.—If a direct-current voltage of 24 volts is desired, what is the lowest alternating-current voltage that will suffice?

SOLUTION.—Substituting in formula 2,

$E = .707 \times 24 = 17$ volts. Ans.

33. Potential Regulators.—If it is necessary to vary the direct electromotive force on the dynamo side of a rotary converter through any considerable range, it is also necessary to vary the alternating electromotive force applied to the motor side. This is frequently accomplished by using transformers provided with a number of taps from the secondary windings, so that the turns can be cut in or out, thus varying the alternating electro-motive force applied to the rotary converter. Another plan is to insert special transformers, called **potential regulators,** between the secondary of the transformers or supply mains and the collector rings of the rotary.

34. Operation From Direct-Current Side.—When a rotary is supplied with direct current, it runs as a direct-current motor and its behavior is quite different from that when it is operated from the alternating-current side. Weakening the field will cause the armature to speed up, and strengthening

the field will slow it down as with any direct-current motor. Altering the field strength will not change the alternating electromotive force because every change in field strength is accompanied by a change in speed, and the alternating electromotive force that is generated in the conductors remains the same. In order to vary the alternating electromotive force delivered by the alternating-current dynamo side, it is necessary to vary the electromotive force applied to the motor armature by the use of an adjustable resistance in series with the armature

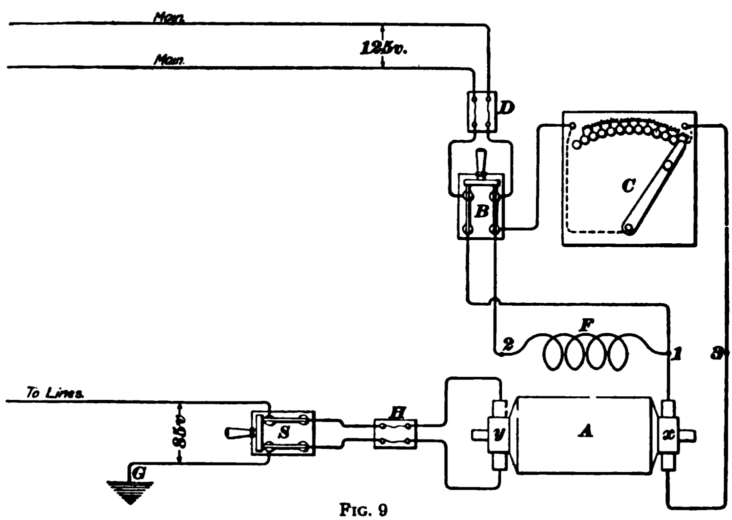


FIG. 9

only, or else regulate the potential in the circuit leading from the alternating-current side.

35. Converter and Supply-Circuit Connections.—One method of connecting a converter to constant-potential mains is shown in Fig. 9. The wires from the mains leading to the converter are connected through a fuse block *D* to a double-pole knife switch *B*. One end of the shunt field *F* is connected to one terminal *1* of the converter, to which is also connected one brush on the *x* commutator. The other field terminal is connected to the other terminal *2*. The other brush on the commutator *x* leads to the terminal *3*, to which it is connected to the starting rheostat *C*. As soon as the main

switch B is closed, a current will flow through the snunt field F, and thus magnetize it before any current flows through the armature A (the first contact at the left on the rheostat being a dead point). When the rheostat arm is moved toward the right, a current flows through the armature and a strong starting effort is produced, because the field is already magnetized. As the handle is then moved slowly to the last point on the right, the converter attains its full speed. A switch S and a fuse H are placed on the side of the converter that supplies the desired current. The switch S should not be closed until the machine is running at its usual rate.

36. The voltage between the two brushes on the y commutator side of the converter may be controlled by an adjustable resistance in the supply mains. Such a resistance or rheostat must be made of wire large enough to carry the whole current for an indefinite length of time without undue heating, and it will take the place of the starting rheostat or box C. As starting rheostats for motors are not designed to carry the current continuously, they are not suitable for regulating the voltage of a converter.

DOUBLE-CURRENT GENERATORS

37. If a machine constructed in the same way as a rotary converter is driven by a motor or engine by means of pulleys and a belt, it will deliver direct current from the commutator end and alternating current from the collector rings. A machine so operated is called a **double-current generator.** The full output of the machine may be delivered as direct current, as alternating current, or partly as one and partly as the other, provided, of course, that the combined output on the two sides does not exceed the capacity of the machine.

OVERLOAD AND UNDERLOAD DEVICES

38. When storage batteries are charged from a lighting circuit or from a dynamo or converter, there should be used in the charging circuit going to the batteries a device that will automatically open the circuit if the current becomes too

large, or too small, or if it drops to zero. Such a device is called an **automatic overload-and-underload switch.** Its first duty is to prevent the batteries from being charged at too high a rate; it also protects the charging machine or electric-light mains from being overloaded. Such a switch should be used in the charging circuit of all storage batteries, in which case no main-line fuses are necessary. A magnetic overload device is much preferable to a fuse, because it is more reliable and can be more quickly and more easily reset.

The object of having the circuit automatically opened when the current drops to zero is to keep the storage batteries from discharging back through the charging circuit, which might cause one of several objectionable things to happen. The current, if discharged back into a dynamo or converter, will tend to run the machine as a motor, thus wasting the energy of the battery, or the armature might be burned out by the excessive current discharged back through it from the batteries. Furthermore, the cells may be injured by the high rate at which they discharge back through the charging circuit. For, when the machine stops running, the storage batteries will be short-circuited by the low resistance of the armature winding. A device that will open the circuit when the current drops to zero is, therefore, very desirable. Of course where there is an attendant constantly on hand watching the charging of the cells, such a device may not be so necessary.

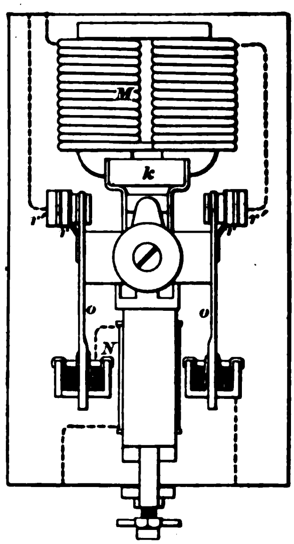


FIG. 10

39. Cutter Overload-and-Underload Device.—An underload-and-overload circuit-breaker is shown in Fig. 10. This device is double pole, that is, it opens both sides of the circuit like a double-pole knife switch, *o* being the knife blades.

There are two electromagnets M and N, both connected in series with the main circuit; N, which is nearly hidden from view, may be called the overload, and M the underload magnet. The poles of the underload magnet M are bridged by the iron keeper k. As long as a current flows through the circuit, this keeper k is held against the pole pieces of the magnet M; but if the current drops to zero, the keeper k is released. This releases a trip and the switch is thrown open by a strong spring. The magnet M may also be designed to release the keeper k if the current falls below any given value.

If, on the other hand, the current becomes excessive, the magnet N draws an iron plunger (not shown in Fig. 10) toward it with sufficient force to release the trip, and the spring, as before, throws open the switch. The main contacts are protected against the ruinous effects of an arc at the breaking of an excessive current by causing the current to be finally broken between flat carbon sticks r and r'. These carbon sticks when worn out can be easily replaced by new ones.

RECTIFIERS

GENERAL PRINCIPLES OF ELECTROLYTIC RECTIFIERS

ELECTROLYTIC RECTIFIERS

40. It has been known since 1856 that an electrolytic cell will act as a valve to an alternating current if it has an aluminum electrode and a suitable electrolyte; the other electrode may be of almost any other metal. Current will readily pass toward the aluminum electrode, but scarcely any current will flow from the aluminum electrode through the electrolyte to the other electrode. Such a cell properly connected with a source of alternating current and a storage battery will allow the storage battery to be charged by impulses of current always in the same direction but separated by equal periods of time during which practically no current will flow. Thus, only one-half the alternating-current impulses will be utilized.

There is, of course, some leakage of current in the wrong direction and the cell becomes heated more or less, depending on the size, construction, and the strength of current passed through it, and the efficiency decreases rapidly as its temperature rises. Moreover, the solution must be renewed when it has been exhausted. Nevertheless, the electrolytic rectifier may be advantageously used in place of primary cells, for charging small storage batteries and for lecture and experimental work.

41. When in operation a very thin coating of aluminum oxide is said to cover the aluminum plate and to prevent current passing from the aluminum to the electrolyte. This peculiar behavior of aluminum in certain electrolytes is termed its *asymmetrical resistance;* that is, it has a very high resistance for current flowing in the opposite direction. For the other electrode iron, lead, carbon, or any conducting material that is not acted upon chemically by the electrolyte may be used. For the electrolyte a number of substances may be used. Probably the cheapest and most easily obtained is a solution of one part of ordinary baking soda (bichromate of soda) to sixteen parts of water. This, however, is not a very efficient solution and tends to make the aluminum deteriorate more rapidly than other substances. Better solutions are made of ammonium carbonate, ammonium oxalate, or ammonium phosphate, the latter being preferred.

A very good arrangement consists of an anode of sheet aluminum, which is inclined to allow the gases (usually hydrogen) to leave the surface of the plate more readily; a cathode of lead of larger surface than the anode and with a rough surface that is capable of being formed like a storage battery plate; and a concentrated solution of neutral ammonium phosphate.

CONNECTIONS OF ELECTROLYTIC RECTIFIERS

42. To use both the positive and negative waves, or impulses, of the alternating current, two or more cells should preferably be employed, although one cell with three electrodes may be used. In Fig. 11 is shown an arrangement for

connecting four rectifying cells *a*, *b*, *c*, and *d* to an alternating-current circuit *f g* for charging a storage battery *e*. The small electrodes represent aluminum and the larger ones lead. When *g* is positive, current flows in the direction represented by the full-line arrows; when *f* is positive, current flows in the direction represented by the dotted arrows. In both cases the

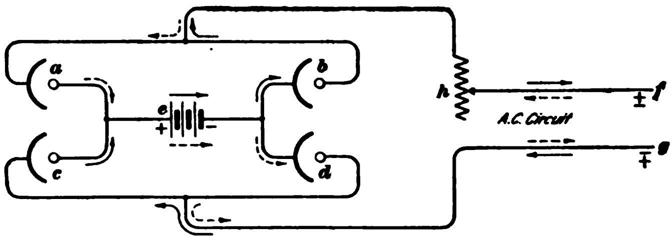


FIG. 11

direction is the same through the storage-battery circuit and the storage battery may thus be charged. A regulating or other suitable substance may be used at *h*.

43. In Fig. 12 is shown an arrangement requiring three cells, one of which *b* must have three electrodes, two lead and one aluminum, and should be about twice as large as either of the others *a* or *c* because twice as much current (both waves)

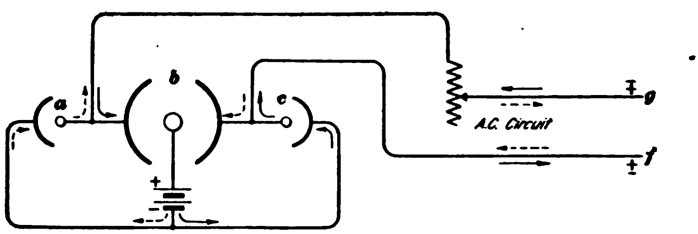


FIG. 12

is rectified in *b*. The full-line arrows show the path of the current when line *g* is positive and the dotted arrow when line *f* is positive.

44. Where only two cells, or one cell with three electrodes, are used a reactance coil or the secondary winding of a transformer with a connection to the center is essential in each case. When, as in Fig. 13, the two aluminum electrodes of the

rectifying cells *a* and *b* (or the one aluminum electrode in a three-electrode rectifier) are connected to the positive terminal of the storage battery and the two lead electrodes are connected to the alternating-current lines, the current flows as indicated. When *g* is positive, the current returns from the storage battery through the left half of the reactance; and when *f* is positive the current returns through the right half of the reactance. A reactance is used because a greater impedance across the two lines *f* and *g* can be more cheaply secured than if a non-inductive resistance is used. This is not a very efficient arrangement for some current, of course, flows directly through the whole reactance from one alternating-current line to the other. The greater the reactance, the less will be the current wasted; on the other hand, it must not be too large or not enough charging current can be obtained.

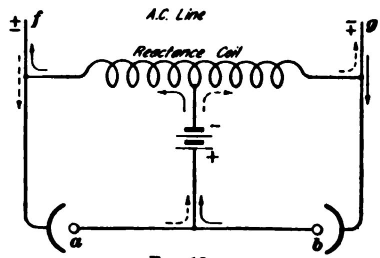


FIG. 13

With an economical arrangement, the efficiency may reach 75 per cent. on a 110-volt, 50-cycle circuit, but it is usually lower. From 110-volts alternating, a direct current at 80 to 90 volts may be obtained.

45. For securing 3 to 6 amperes at 15 to 25 volts from a 30-volt alternating-current circuit, the aluminum plates may be about 3 in.×5 in., separated ½ inch from lead plates which may be about 4 in.×5 in., and the jars about 6 in.×4½ in.×3 in. If this rectifier cell is used very long some arrangement, such as running cold water through a tube passing through the solution, should be provided to keep the solution from becoming too warm. By properly connecting rectifying cells in series or multiple, they may be used for obtaining almost any voltage or current. When used for charging storage batteries, the latter cannot discharge into the supply circuit when the alternating electromotive force is stopped, as the electrolytic cells then act as fairly efficient circuit-breakers.

CHURCHER RECTIFIERS

46. Four cells of the **Churcher electrolytic rectifier** replaced, in 1906, 100 sal-ammoniac cells; another rectifier replaced 58 cells used for operating Western Union clock circuits; and a third rectifier replaced 35 cells operating stock tickers and requiring replenishing twice a week. These Churcher rectifiers produced a direct-current at 50 volts from a 110-volt alternating-current circuit. The **Churcher electrolyte** consisted of 1 pound of ammonium phosphate, 1 ounce of potassium phosphate, 1 ounce cream of tartar dissolved in enough water to nearly fill the glass jar. Three electrodes were used. The center aluminum electrode was connected to the center of the secondary winding of a transformer and each end of this winding was connected through an ordinary, carbon, incandescent, 16-candlepower lamp to one of the lead electrodes.

RICHTER RECTIFIER

47. In 1907, the E. L. Richter Electric Company introduced the electrolytic rectifier shown in Fig. 14. The electrolytic cell *a* consists of a circular iron tube about 4 inches in diameter and 2 feet in length, with which is connected a sheet-iron radiator through which the electrolytic solution circulates to keep cool. The aluminum electrode is a rod hanging in the center of the iron tube.

In a 10-ampere rectifier operated at 133 cycles, the temperature of the solution reaches about 100° F. and much lower for a 60-cycle current. From a 110-volt alternating-current circuit there is produced a direct-current at 80 volts. An adjustable rheostat is provided to vary the direct current from 1 to 10 amperes, which is indicated by the ammeter at the top of the switchboard. A larger type is designed for producing direct current up to 25 amperes.

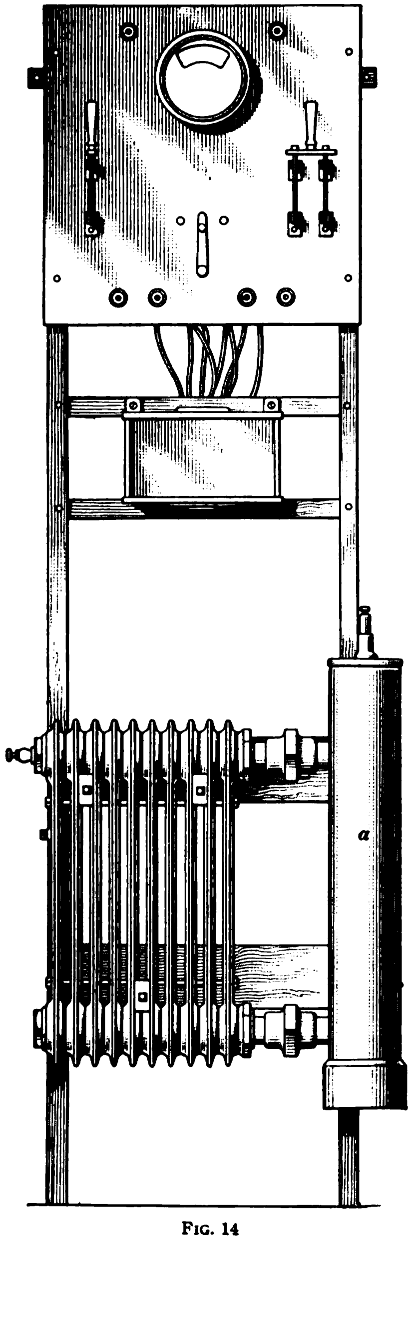
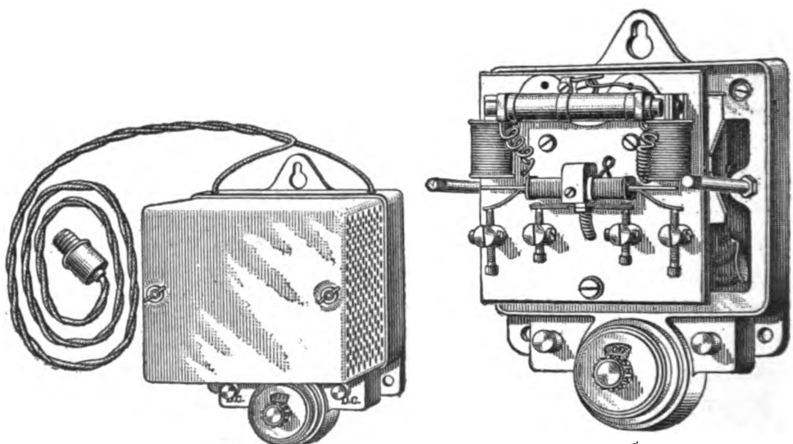


FIG. 14

MECHANICAL OR VIBRATING RECTIFIERS

48. Mechanical, or vibrating, rectifiers are being successfully used for charging small storage batteries of three or four cells each, such as are used for lighting and ignition in automobiles. Similar storage batteries should be useful for supplying current to operator's telephone transmitters and for sounders in small offices where only alternating current for lighting is available. These rectifiers consist essentially of switches that open and close automatically in synchronism with the alternating current being rectified in such a way as to



(a) (b)

FIG. 15

cut out the half waves in one direction or better yet to rectify these alternate half waves, so that in one part of the circuit current impulses flow in one direction only.

49. Fig. 15 shows the appearance of one such vibrating rectifier; (*a*) is the complete device and (*b*) the same with the cover removed. Fig. 16 shows the connections of the device. The secondary *3 – 5* of a small transformer is connected through a regulating resistances *b* and *c* to two stationary platinum tipped contacts *a′* and *a*. Above these two contacts are two platinum-tipped vibrating contacts carried by the pivoted core

of a direct-current magnet. This core serves as the armature of two alternating-current magnets connected in series across one-half of the transformer secondary. The alternating-current magnets are so connected that both downwardly projecting poles have the same magnetic polarity at any given instant; that is, both are alternately positive and alternately negative as the current reverses. The vibrating armature is polarized by a direct-current winding connected with the battery being charged, one end of the armature always being positive and the other end always being negative. Each end is, therefore, alternately attracted and repelled by the poles of the alternating-current magnet above, thus keeping the armature vibrating in synchronism with the alternating current, and making contact, first on one side and then on the other with the fixed platinum points.

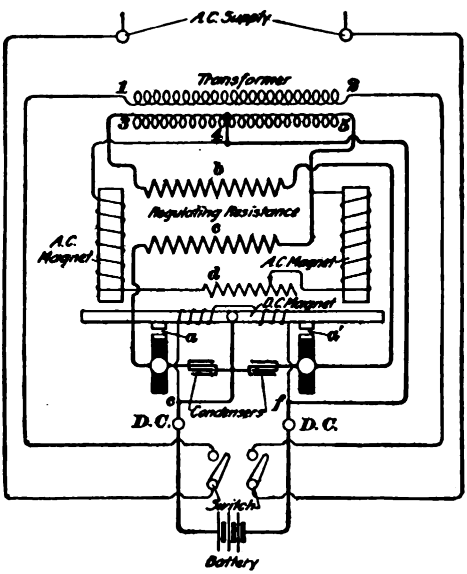


FIG. 16

The closing of these contacts are so timed as to rectify each negative half wave, giving a pulsating direct voltage and current, as represented in Fig. 17. Here, line $a-b$ represents zero voltage and line $c-d$ the battery voltage. Only the rectified voltage above the battery voltage is effective in charging the storage battery; that is, only the portion represented by the curves above line $c-d$ is useful in charging the storage battery. The contacts are, therefore, timed to be closed at instants corresponding to points c and f, and to break at instants corresponding to points e and d. If either pair of contacts are closed at points below

battery voltage, the battery will discharge through the rectifier. The period represented by the space $e-f$ lapses between the instant contact is broken on one side and made on the other side by the vibrating armature. In Fig. 16, one direct-current impulse passes from *3* through $b - a'$ - armature - armature-pivot - e where it divides through the battery and direct-current magnet coils to f, then to *4*. The other impulse passes from *5* through $c - a$ - armature - e, dividing through battery and direct-current magnet coils to f, then to *4*.

50. If contacts are made and broken at the exact instant of zero current, no sparking occurs. A resistance d connected in series with the two alternating-current magnet coils can be adjusted to assist in obtaining sparkless operation; the condensers also reduce the tendency to spark if the adjustment is

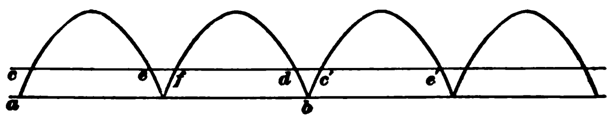


FIG. 17

not exact. The armature itself serves as part of the electric circuit, and springs, which are shown in Fig. 15 (b), keep the contacts opened when the rectifier is not in operation, thus preventing the battery from discharging through the platinum contacts. This rectifier delivers current to the battery in the right direction regardless of the connections of the battery, because the battery polarizes the armature in the proper direction no matter how it is connected to the direct-current magnet. Therefore, no attention need be paid to the polarity when making connections between the battery and the direct-current binding posts of the rectifier. This rectifier utilizes both half waves by reversing alternate waves. If the supply circuit is interrupted temporarily, the rectifier restarts automatically when the circuit is restored. Other vibrating rectifiers send alternate half waves through the direct-current circuit and cut out this circuit while the alternate half waves pass through the rectifier. Such rectifiers are consequently only about half as efficient as the one described.

POWER EQUIPMENT
(PART 3)

RECTIFIERS—(Continued)

MERCURY CONVERTERS

PRINCIPLES OF MERCURY CONVERTERS

1. Definitions.—A **mercury converter,** or **mercury-arc rectifier,** is a device for converting alternating to direct current without the use of vibratory or rotating parts. It consists essentially of a sealed glass vessel from which much of the air has been removed but which contains some mercury that is vaporized when an arc exists between the terminals, or **electrodes.** Mercury is used because this metal ordinarily remains in a liquid state, is comparatively easy to vaporize, and is not excessive in cost. The Cooper-Hewitt Electric Company formerly made such a device, which it called a *mercury-vapor converter.* This type of converter is now made by the Westinghouse Electrical Manufacturing Company. The General Electric Company calls the apparatus it makes a *mercury-arc rectifier.* Mercury converters are very useful for charging storage batteries from alternating-current mains and have certain advantages over motor generators, dynamotors, and rotary converters, which in small sizes are not very efficient and are apt to require more attention.

2. An **electric,** or **voltaic, arc** is a hot luminous flame in the air space or gap across which an electric current is passing

between two electrodes. It is formed by breaking a circuit in which a current is flowing; if the gap is not too long, the arc may be maintained continuously, or until it is purposely suppressed (1) by being blown out by a jet of air, (2) by the repelling effect of a magnet (3), or by stopping the current flow in some other way. After the arc has been suppressed, the same potential difference that maintained it cannot reestablish it; in fact, the arc can be reestablished only by greatly increasing the potential difference between the electrodes or by shortening the gap. When the arc is established, the intense heat vaporizes a portion of the material of the electrodes and the vapor acts as a conductor across the gap. The **anode** is the electrode to which the current flows from the external circuit and the **cathode** is the electrode from which the current flows into the external circuit.

3. Metallic vapor is obtained by vaporizing a metal. When heat is applied to a piece of ice, the ice is first melted, or turned to a liquid, then if the heat is great enough this liquid is turned to a vapor. The application of sufficient heat to any other solid produces similar results. For example, it is possible to melt iron and then to turn this liquid iron into vapor.

Mercury, which is often called quicksilver, is a silver-white metallic element that is liquid at ordinary temperatures. By lowering its temperature sufficiently it becomes a solid, that is, it freezes; raising the temperature of liquid mercury sufficiently readily vaporizes it.

A **vacuum,** as commonly understood, is a space from which the air has been more or less removed; the more nearly the air has been completely removed, the more perfect is the vacuum. A perfect vacuum is practically impossible to produce.

4. Theoretical Action of Mercury Converters.—The action of a mercury converter may be explained by the aid of Fig. 1, in which *b* represents a battery, ***d*** a closed glass tube from which the air has been exhausted and that has sealed in opposite ends the wires that terminate inside the tube in the

electrodes *a* and *c*. The anode *a* may be iron or graphite; the cathode *c* is liquid mercury.

If by some means an electric arc is started from the anode *a* to the cathode *c*, current will flow in the direction indicated by the arrows. To start the arc either the difference of potential between the anode and cathode must be raised to an excessive value, perhaps 25,000 volts, or the tube must be shaken or tipped until the mercury forms a continuous stream between the two electrodes, and is then righted again to break the stream. As soon as the stream is made continuous, the current follows it, so that when the stream breaks, an arc is formed. The heat of the arc immediately vaporizes some of the mercury and the vapor reduces the resistance of the path between the two electrodes sufficiently to allow the maintenance of an arc and, therefore, the flow of current from the anode *a* to the cathode *c*. As long as the current flow is not interrupted, a comparatively low voltage will maintain the arc.

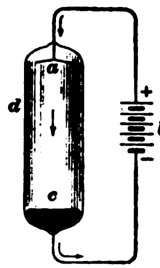


FIG. 1

5. The voltage required to maintain the arc depends on the length of the arc and not on the strength of the current; that is, in a given tube the voltage across the arc will remain practically constant, even if the current strength varies. This may be explained by assuming that the greater the quantity of current, the more rapid is the formation of mercury vapor; hence, the greater is the conductivity of the path between the electrodes. However, too much vapor will smother the arc. The vapor condenses on the walls of the vessel and runs to the bottom; so that if the vessel is not large enough to afford sufficient condensing surface, the vapor soon becomes so dense that the arc goes out.

6. Arrangement of Electrodes.—With the apparatus arranged as shown in Fig. 1, if the condensing surface is sufficient, an arc once established will continue as long as the necessary potential difference for maintaining the arc is preserved between the electrodes; but if the arc is allowed to cease,

even for an instant, it will not start again, unless the stream of mercury is reestablished by shaking or tilting or by an excessive increase in the applied electromotive force. No matter how quickly the circuit is opened and again closed, the arc will not start again. When an alternating-current dynamo *e* is connected to the terminals *a* and *c* of the glass vessel, arranged as shown in Fig. 2, even the small intervals in each current cycle during which the current is zero, are sufficient for the production of the conducting vapor to cease and for the arc to go out. It has been determined that, even with a 10,000-cycle alternating current, which gives 20,000 interruptions per second, a frequency far beyond any used in commercial work, the reversals are not quick enough to maintain the arc. No ordinary, commercial, single-phase, alternating current will, therefore, support an arc with the arrangement of electrodes and tube shown in Fig. 2.

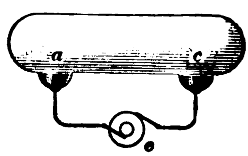


FIG. 2

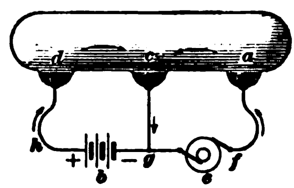


FIG. 3

7. Combination of Battery and Dynamo.—Almost all the resistance to the starting and maintaining of an electric current through a mercury-vapor tube occurs at the cathode, therefore if enough current can be made to flow continuously through the cathode to maintain the supply of conducting vapor, the arc will be maintained. Fig. 3 shows a tube with three mercury electrodes *a*, *c*, and *d*, a battery *b*, and a single-phase alternator *e*. The current from the battery *b* through $h-d-c-g$ is made strong enough to maintain the supply of conducting vapor after it is once started so that the resistance at the cathode *c* is kept low. The current from the alternator that flows from the anode *a* to the cathode *c* can pass, but no current can pass from the cathode *c* to the anode *a*; that is, the device acts as a valve that readily allows current to pass in one

direction but not in the other. The impulses that tend to flow from the cathode c to the anode a are suppressed by the high resistance of the anode a.

8. The disadvantage of the arrangement shown in Fig. 3 is that only one-half the alternating current passes through it. In Fig. 4 is shown an arrangement by which the negative impulse of an alternating current can be made to flow in the same direction as the positive impulse; in other words, the alternating current is rectified and the entire current used. The tube has four electrodes; d is an auxiliary anode through which current enters the tube from a battery b, a and a' are the anodes to which the wires from the dynamo e or a transformer are connected, and c is the cathode.

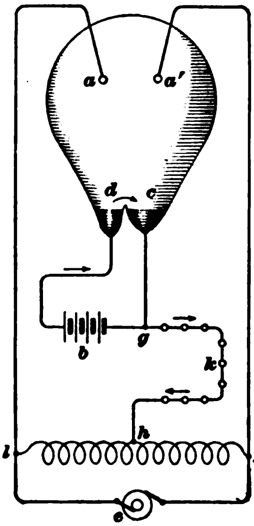


FIG. 4

The action is started by tilting the tube until the mercury forms a stream between the electrodes d and c, so that current from the battery b can follow the mercury from one electrode to the other; then the tube is righted to break the continuity of the mercury. An arc is thus immediately formed from d to c, which maintains the supply of conducting vapor. Impulses of one polarity then flow from the source of alternating current e through $l-a-c-g-k-h-f-e$ and impulses of the opposite polarity through $f-a'-c-g-k-h-l-e$. Thus current flows only in one direction through $g-k-h$, in which circuit may be located direct-current devices as represented by the circles. Comparatively little of the alternating current flows from l to f or vice versa on account of the high impedance of this coil. The direct current thus obtained from the alternator is of a pulsating character and

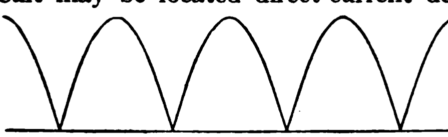


FIG. 5

may be represented by the curve in Fig. 5. The direct current represented by this curve will not maintain the arc without a battery, for at the end of each half wave this pulsating current falls to zero.

9. Single-Phase Converter.—Fig. 6 shows an arrangement by which the arc may be maintained by single-phase alternating current only, no battery being required. A choke coil *l* is connected in the direct-current circuit between the cathode *c* and the middle point *h* of an autotransformer coil. The choke coil delays each successive impulse of current until the next impulse from the other electrode has started; that is, it makes each direct-current impulse lag so that the half waves overlap one another.

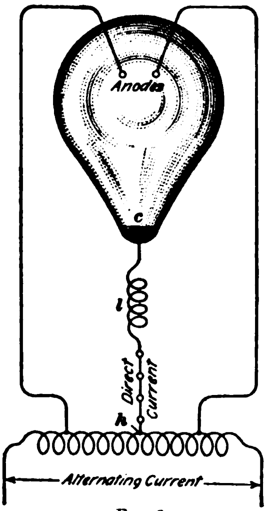


FIG. 6

The direct current from *c* to *h*, Fig. 6, at no time falls to zero, but consists of a series of slight impulses. For most purposes, a direct current having slight pulsations is not objectionable, but for charging storage batteries while supplying current to central-energy telephone systems, the pulsations should be smoothed out as much as possible.

STARTING DEVICES

10. Difficulty in starting an electric arc is experienced whether the arc is started in air or in a metallic vapor. It could be done by bringing the electrodes together, as when starting the arc between ordinary carbons for lighting purposes, and then separating them after the current begins to flow. The usual method of starting, however, is to tilt the vessel until the mercury of the cathode comes in contact with an anode and forms a bridge over which the current temporarily passes from the anode to the cathode; as soon as the

resistance of the cathode is broken by the production of a conducting vapor, the alternating current will maintain the arc, provided that the inductive resistances are so arranged as to produce the proper phase relation. For starting purposes, the tubes in commercial use for mercury converters have an auxiliary mercury anode near the cathode.

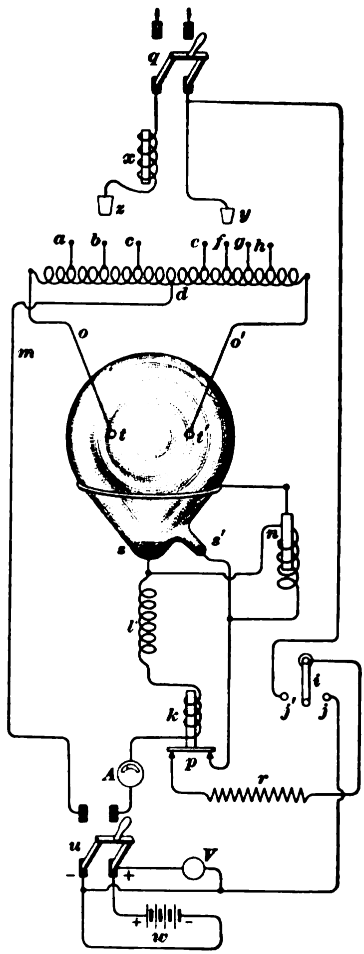


Fig. 7

COOPER-HEWITT MERCURY-VAPOR CONVERTERS

11. General Description. — The Cooper-Hewitt mercury-vapor converter made for charging storage batteries consists of a bulb, a panel, a frame, and an autotransformer. A simplified diagram of its connections is shown in Fig. 7. If the direct-current load is a storage battery, which is commonly called a *live load*, the converter is started by turning the switch lever *i* to the right-hand contact *j* and closing both the alternating-current and the direct-current switches *q* and *u*. Current then flows from the positive terminal of the storage battery *w* through the ammeter *A* – cut-out magnet *k* – sustaining coil *l* – tilting magnet *n* – cut-out switch *p* – starting resistance *r* – starting switch *i* – *j* to the negative terminal of the battery. This current is too weak on account of the resistance *r* to operate the cut-out magnet *k*. The tilting magnet *n*, however, tilts the bulb until the mercury connects the

two electrodes s and s', then the current flows through the mercury instead of through the tilting magnet. This magnet n is thereby so weakened that the bulb falls back to its upright position, thus breaking the stream of mercury between the electrodes s and s'. The high resistance of the arc between these electrodes s and s', however, causes the bulb to be tilted again almost immediately, and the arc is then transferred to the electrode s and the main anodes t and t'.

12. The current is then forced back through the sustaining coil l – cut-out magnet k – ammeter – storage battery from which the returning current flows to the neutral point d of the transformer. This current is strong enough to operate the cut-out magnet k and open the circuit through the resistance r and the starting cathode s'. The electrode s then becomes the cathode and remains such until the arc is in some way broken. When starting the converter, the electrode s is used as an anode, the current passing from the anode s to the cathode s'.

13. Voltage Regulation.—The main voltage regulation for the direct current is obtained by placing the plugs z and y in connection with suitable taps a, b, c, e, f, g, and h along the autotransformer coil; the voltage with these plugs in any position may be further varied somewhat by varying the position of an iron core in the regulating coil x, which varies the impedance of the coil. The plugs y and z are different in size so that z can only be placed in a, b, and c and y in e, f, g, and h. When the apparatus is in operation, the resistance r and tilting coil n are both cut out.

14. Bulb.—The bulb of the Cooper-Hewitt mercury-vapor converter is shown in Fig. 8. It is an exhausted glass vessel about 9 inches in diameter, and is large enough for the surplus vapor to condense on the inside surface and run back to the electrode in the bottom. All wires leading into it are sealed air-tight in the glass walls. The iron anodes t and t' are almost completely enclosed in bottle-shaped glass tubes to prevent the formation of arcs between them. Openings in the tubes, opposite the sides of the anodes farthest from each

other, permit arcs to pass from the anodes t and t' to the cathode s; s' is the auxiliary or starting cathode. After the mercury for the cathodes s and s' is inserted through a glass tube in the top of the bulb, the air is exhausted from the bulb, which is then sealed, a tip being left on the end. The terminals o and o' are used for connecting the converter to the alternating-current supply circuit.

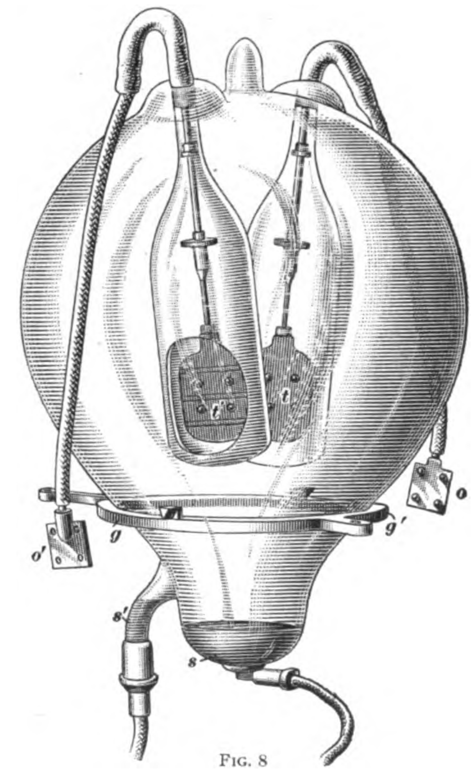


Fig. 8

When assembled in its frame, the bulb rests in a ring g and g' that is supported on knife edges so that the bulb, when the starting switch is closed, may be automatically tilted by the tilting magnet until the mercury in the starting anode comes in contact with that at the cathode. The circuit through the tilting magnet is then automatically opened, the bulb rights itself, and the arc starts.

15. Panel and Frame.—Fig. 9 shows the complete standard type PA converter, including the front of the panel and the cage used to enclose the apparatus. The cage occupies a space 15 inches by 22 inches and is 22 inches high. The output is from 6 to 30 amperes direct current at any voltage from 50 to 115, as explained later.

On the front of the marbleized slate panel are mounted a direct-current voltmeter V, a direct-current ammeter A, a

regulator handle x that turns a worm-wheel to move a plunger or core in or out of a choke coil connected in the alternating-current supply circuit, a switch q in the alternating-current circuit, a switch u in the direct-current circuit, and a three-way starting switch i. Under the table, or bench, on which

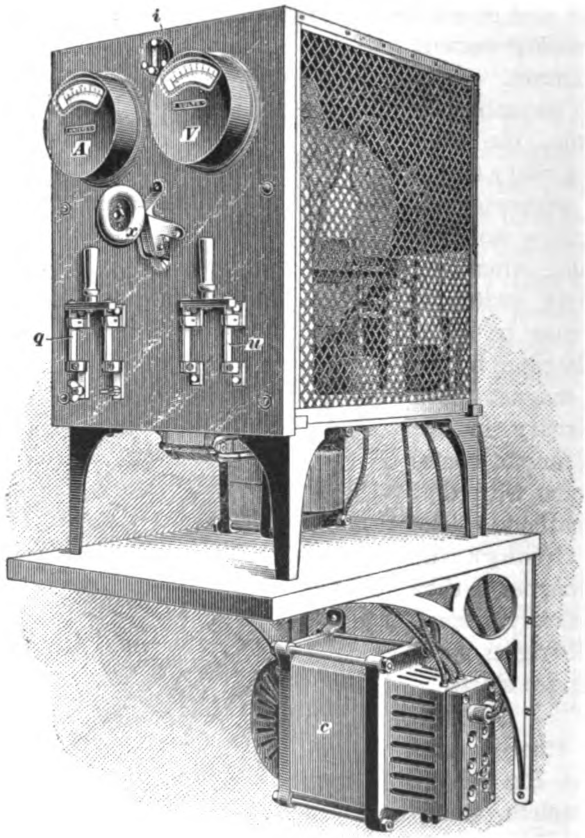


Fig. 9

the iron frame stands, is shown the autotransformer c, with a plug board e attached and into which two of the wires from the connection board may be plugged.

16. Fig. 10 shows the back of the panel and the apparatus with the cage removed. On the back of the panel are the

terminals of the instruments and switches and the starting resistance *r*, which is wound on porcelain tubes. The panel is supported on a cast-iron frame, which also carries the supporting mechanism for the bulb; the regulating coil *x*, the core of which is moved by means of the hand wheel on the front of the board; the tilting magnet *n*; the sustaining coil *l* for steadying the direct

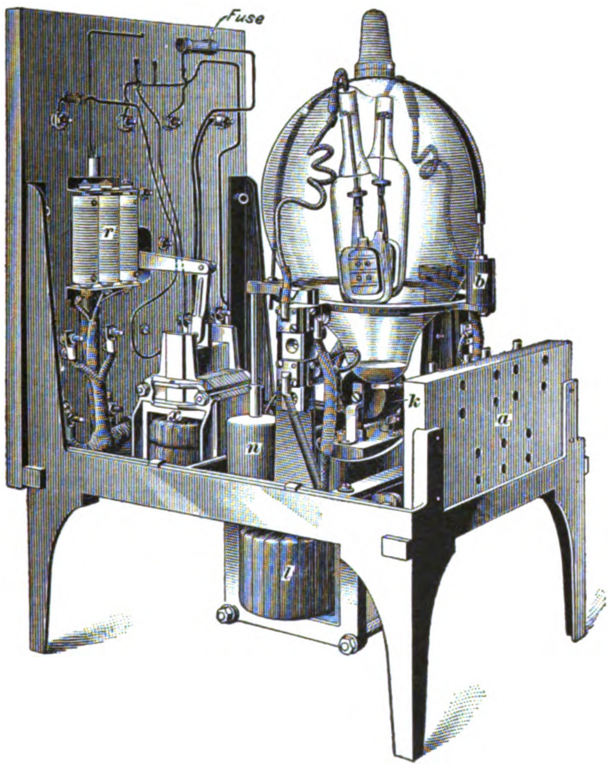


Fig. 10

current and causing the necessary lag of the rectified impulses; the cut-out magnet *k* and a connection board *a*, having lugs for seven circuits or fourteen wires. A weight *b* helps to return the bulb to the vertical position after it has been tilted.

Five wires are connected to the autotransformer; these, with the two alternating-current supply wires, constitute seven

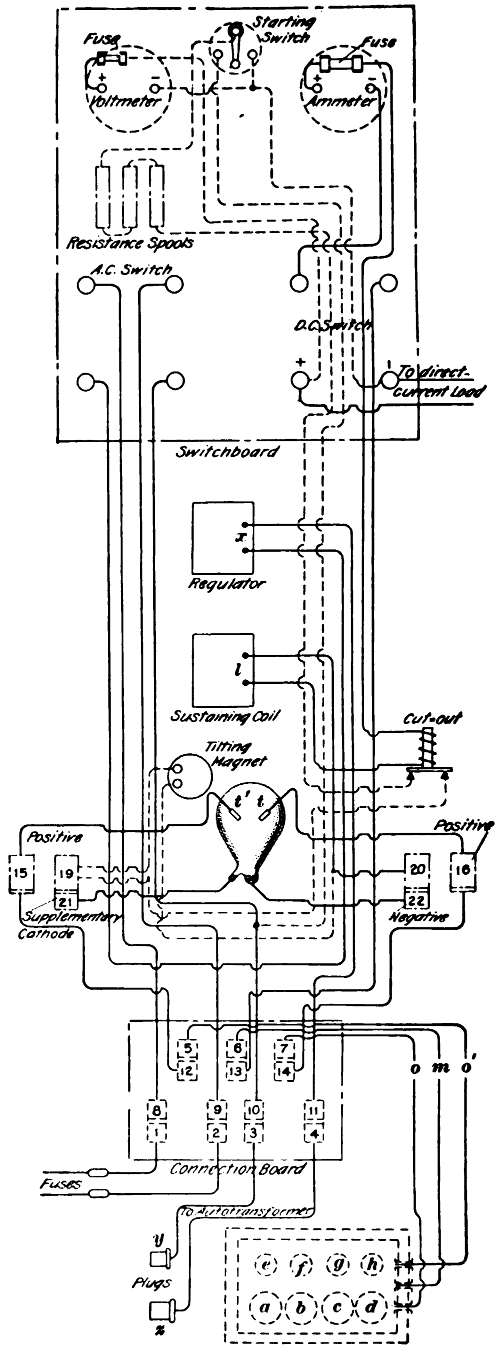

Starting Switch
Fuse
Fuse
Voltmeter
Ammeter
Resistance Spools
A.C. Switch
D.C. Switch
To direct-current Load
Switchboard
x
Regulator
l
Sustaining Coil
Cut-out
Tilting Magnet
t'
t
Positive
15
19
21
Supplementary Cathode
Positive
20
16
22
Negative
5
12
6
13
7
14
o
m
o'
8
1
9
2
10
3
11
4
Connection Board
Fuses
To Autotransformer
y
Plugs
z
e
f
g
h
a
b
c
d
Autotransformer Plug Board

FIG. 11

of the wires leading to the connection board. The other seven connected with these on the board, lead to various parts of the converter apparatus. The frame work supporting the converter, instead of being cast with supporting legs as shown, may be provided for bolting to a wall, and the autotransformer may be placed at any convenient point near-by.

17. Converter Diagram.—Fig. 11 is a diagram showing the principal parts of the converter laid out in a horizontal plane and also showing the connections. The anodes *t* and *t'* are connected to lugs *15* and *16*, the starting cathode to lug *21*, which is connected to lug *19*, and the cathode to lug *22*, which is connected to lug *20*. The alternating-current wires are connected through suitable fuses to lugs *1* and *2* on the connection board, these being connected to lugs *8* and *9*, respectively. The path of the alternating current may be readily traced to the alternating-current switch on the switchboard. Lugs *10* and *11* are connected, respectively, to lugs *3* and *4*; and from these extend flexible leads terminating in the plugs *y* and *z* that may be inserted into various holes in a plugboard attached to the autotransformer according to the voltage transformation desired. The holes *a*, *b*, *c*, *d*, *e*, *f*, *g*, and *h* on the transformer plugboard correspond to the similarly lettered taps in Fig. 7. Lugs *15* and *16* are connected, respectively, to lugs *12* and *14*, which, in turn, are connected to lugs *5* and *7*. From lugs *5*, *6*, and *7*, wires *o* and *o'*, and *m* extend to the autotransformer—wires *o* and *o'* being connected to the extreme ends of the transformer coil and wire *m* to the middle or neutral point. These wires are lettered the same as in Fig. 7. Lug *13* is connected to lug *6* and also to the direct-current switch on the switchboard.

The two lower terminals of the direct-current switch are connected to the load—which may be a storage battery, a motor, or lights—and also to the voltmeter, so that if the load is a storage battery, its voltage may be read before the switch is closed. One terminal of the ammeter is connected to the direct-current switch and the other through the cut-out magnet and the sustaining coil to lug *20* on the connection board, the polarity being plainly indicated by the signs + and −.

The plugs *y* and *z* on the ends of the alternating-current leads differ in size, and the holes in the plugboard of the autotransformer are of similar size, so that it is not possible to insert the plugs in holes in which they are not intended to go. The autotransformer should be set with the plugboard vertical, so that dust will not settle in the holes.

18. Voltage Transformations.—The voltage of the transformed current depends on the positions of the plugs in the holes *a*, *b*, *c*, *d*, *e*, *f*, *g*, and *h* of the transformer plugboard.

TABLE I

PLUG POSITIONS FOR VARIOUS VOLTAGES

Alternating Current Volts 200		Alternating Current Volts 200		Alternating Current Volts 200	
Direct Current Volts	Plugs In	Direct Curernt Volts	Plugs In	Direct Current Volts	Plugs In
80 – 130	*b – f*	95 – 140	*b – f*	105 – 140	*c – g*
75 – 120	*c – g*	90 – 130	*c – g*	100 – 130	*b – g*
70 – 110	*b – g*	85 – 120	*b – g*	90 – 120	*b – h*
65 – 100	*b – h*	85 – 95	*c – h*	85 – 110	*a – f*
60 – 90	*a – f*	80 – 110	*b – h*	75 – 105	*a – g*
55 – 85	*a – g*	75 – 85	*a – e*	70 – 90	*a – h*
50 – 70	*a – h*	70 – 100	*a – f*		
		65 – 95	*a – g*		
		60 – 80	*a – h*		

The various plug positions are given in Table I, which will serve as a guide when choosing the plug combinations for different voltages. The direct-current voltages given are the extremes that may be obtained by means of the hand regulating wheel *x*, Fig. 9, when the plugs are in the positions given.

The order in which the changes are made to raise or lower the direct-current voltage with any alternating-current voltage is the same; for example, the highest direct-current voltage with any alternating-current voltage is obtained with the plugs

in holes *b* and *f* or *c* and *g*, and the lowest with the plugs in holes *a* and *h*. If it is desired to raise or lower the secondary voltage by changing the plugs, the necessary change can easily be made by following the sequence given in Table I. A plug position should be chosen such that the exact voltage desired is obtained with the regulator plunger as far out as possible, thus allowing the best circulation of air in the interior of the regulator. The plugs should never be changed while the current is on.

19. Starting on Live Load.—If the converter is started on a live load, it will not continue to run unless the direct-current voltage of the converter is great enough to force more than about 5 amperes through the storage battery. If the converter starts and then goes out in a few seconds, the regulator handle should be turned to the right to raise the voltage until the arc continues. The converter will run on a lower current when hot than when cold; therefore, if it is desired to run on a low current it is best to start on a higher one and then reduce it by turning the regulator handle to the left when the apparatus is warm. If when charging a storage battery the starting switch is left in the central position, the converter will automatically cut out without injury when the battery voltage rises enough to reduce the charging current to about 5 amperes.

20. Starting on a Dead Load.—If the converter is to be started on a load consisting of incandescent lamps or other resistance, which is termed a *dead load*, the starting switch is moved to the left-hand contact *j'*, Fig. 7, when enough alternating current will flow through the tilting magnet and across the electrodes *s* and *s'* to start the arc. The converter may also be started by hand by tilting the bulb through a slot in the top of the cage. When running on a dead load, the starting switch may be left on the left-hand contact, then if the converter should stop due to the failure of the alternating current from any cause, it will automatically start again when the current returns.

21. Operating the Converter.—When operating a Cooper-Hewitt mercury-vapor converter, the following general instructions and precautions should be observed:

1. Before attempting to start the converter, see that the apparatus is properly set up, that all connections are correctly made and tight.

2. If starting on a live load, first see that the voltmeter reads in the right direction and select a plug position that will give about the required voltage. The positive terminal of the battery should be connected to the side of the switch marked +. See that the starting switch is in the right position; set the regulator with the plunger almost all in, that is, turn the handle to the left almost as far as it will go; and close the alternating-current and direct-current switches. The converter should then start, but if on a live load it may be necessary to increase the current a little, as already explained, in order to make the operation continuous. After the converter is running, the desired current can be obtained by turning the regulator handle to the right for an increase and to the left for a decrease.

3. To stop the converter, put the starting switch in the off-position and open both the alternating-current and direct-current switches, either one first, but the direct-current switch should not be closed for any length of time while the other switch is open.

4. Do not attempt to overload the converter, even for a few moments, or the apparatus may be injured. The maximum capacity is plainly indicated on the name plate and in the manufacturer's instructions.

5. The alternating-current voltage between lugs *5* and *7* on the connection board, Fig. 11, with 220 volts supply is about 350 volts, so that care should be taken to avoid accidental shocks. These terminals are on the bottom of the board where there is ordinarily little likelihood of accidental contact. There are no live contacts on the face of the board, except at the switches, and the voltage there is seldom over 250.

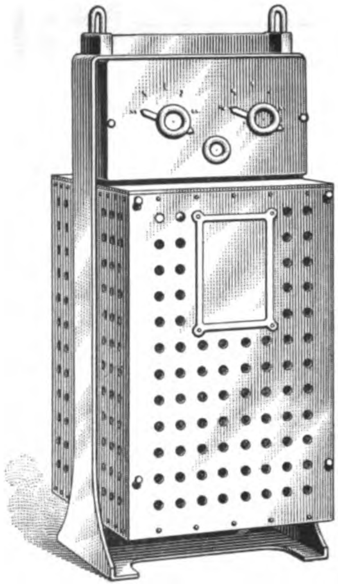


FIG. 12

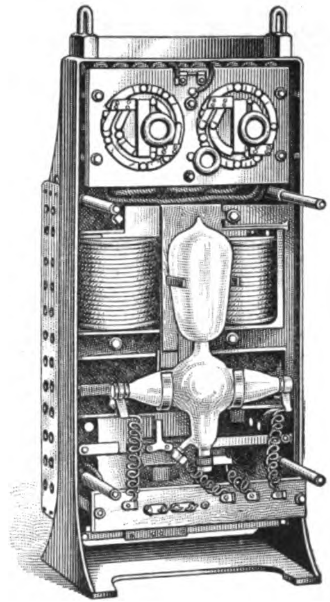


FIG. 13

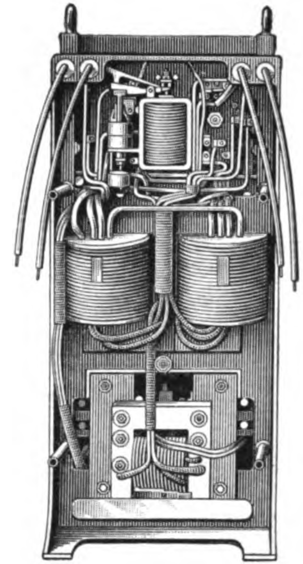


FIG. 14

WESTINGHOUSE MERCURY-VAPOR CONVERTERS

22. General Description.—In Fig. 12 is shown the front view of the type A, Westinghouse mercury-vapor converter; in Figs. 13 and 14 are shown views of the front and the

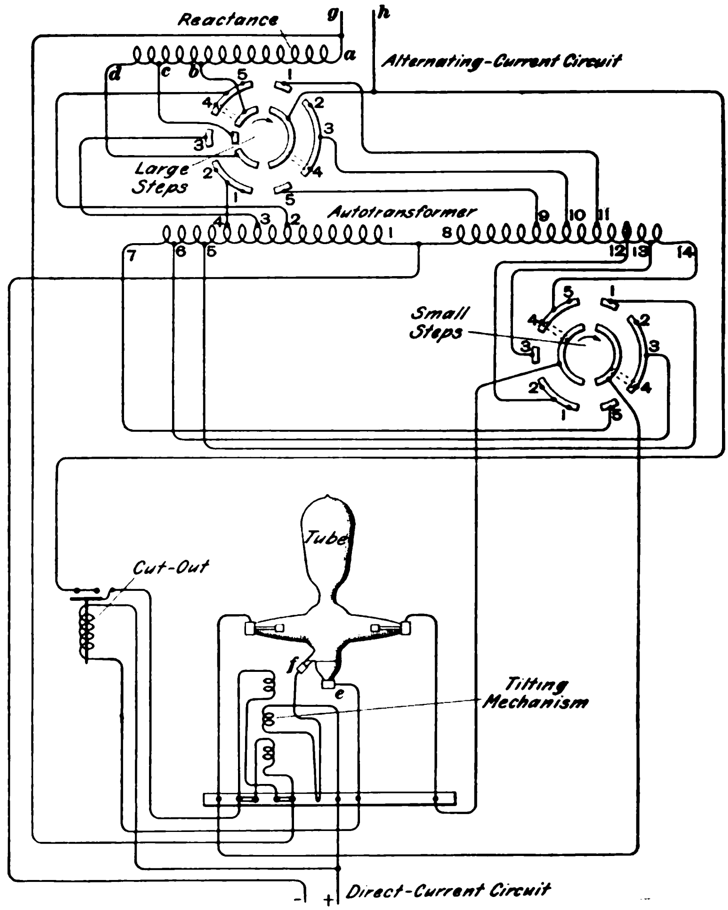


FIG. 15

back with the covers removed. In Fig. 15 are shown the complete connections when this converter is ready to charge a storage battery of 20 to 44 cells, using an alternating current

of 110 volts. This diagram is drawn in accordance with the present tendency to draw all circuits without loops where one wire crosses another. But though lines are not broken when they cross other lines, no lines are considered to be electrically connected unless there is a small black dot at the point of intersection. The type A converter has a maximum direct-current capacity of 30 amperes; other types are made for 5-ampere and 10-ampere capacity.

TABLE II

POSITION OF COMMUTATING-SWITCH HANDLES

Number of Storage Cells	Primary Alternating-Current Circuit		
	105 Volts	110 Volts	115 Volts
	Position of Switch Handles		
20	1 - 3	1 - 2	1 - 1
22	2 - 1	1 - 4	1 - 3
24	2 - 3	2 - 1	1 - 5
26	2 - 5	2 - 3	2 - 2
28	3 - 2	2 - 5	2 - 4
30	3 - 3	3 - 2	2 - 5
32	3 - 5	3 - 3	3 - 2
34	4 - 1	3 - 5	3 - 3
36	4 - 2	4 - 1	3 - 5
38	4 - 3	4 - 2	4 - 1
40	4 - 4	4 - 3	4 - 2
42	4 - 5	4 - 4	4 - 3
44	5 - 1	4 - 5	4 - 4

23. The large-step commutating switch serves to vary the connections that unite the reactance, or inductance, coil with the autotransformer, and the small-step commutating switch is used to vary the connections that unite the secondary of the autotransformer with the bulb of the converter. The inner and outer segments of the two commutating switches are connected together by means of pairs of brushes, the position

of which may be changed by means of the handles, shown in Figs. 12 and 13. Table II indicates the position in which the commutator brushes must be placed for the given alternating-current voltages in order to give the desired direct-current voltage. The position *4 – 4*, for instance, means that the indicators of both commutating switches, as seen on the outside of the case in Fig. 12, must point toward No. 4 on the circles in which they move. The first figure in the table refers to the left-hand commutator, and the second figure to the right-hand commutator in Figs. 12 and 15.

24. After arranging the commutators and verifying the proper position of the indicators, the apparatus is connected with the battery, and the main switch in the alternating-current circuit is closed. The small handle located in the center in the upper part of Fig. 12 must be turned to the right in order to unlock the mechanism that locks the electromagnetic device that tilts the bulb. The alternating current may now be traced, in Fig. 15, from the left-hand wire g through the top and bottom coils of the tilting magnet, which are in parallel, and through the contact of the cut-out device (which is then closed) to the other alternating-current wire h. The tilting magnet tilts the bulb, and at the same time an electromotive force is induced in the center coil of the tilting magnet. This electromotive force produces a current in the local circuit formed by said central coil, the two lower terminals f and e of the converter bulb, the mercury that connects the two ends when tilted and the coil of the cut-out switch. This induced current in the middle coil opposes the magnetism produced by the other two coils of the tilting device and allows a counterbalance to restore the bulb to its vertical position. In this manner the arc is formed and the resistance of the negative electrode reduced. Then a circuit can be formed between either of the two principal anodes and the cathode e, and the continuous current passes from the cathode to the coil of the cut-out switch, which opens the circuit through the upper and lower coils of the tilting magnet, thereby cutting this device out of circuit.

25. When the current exceeds 10 amperes, the direct-current circuit should not be opened before the alternating-current circuit, as otherwise the tilting magnet would tend to keep restarting the bulb. As the battery becomes fully charged, the charging current will diminish on account of the counter electromotive force of the battery itself. In order to prevent the action of the apparatus after the battery has been charged, there is a special mechanism which automatically locks the cut-out switch in the open position when the current falls below 10 amperes. If for any reason the action is interrupted before the battery is fully charged, the operation of the bulb will be automatically restarted as long as the current is greater than about 10 amperes, which shows that the locking mechanism of the cut-out switch is in good order, as this mechanism does not work unless the current has fallen to this limit.

26. Charging Telephone Batteries.—For charging storage batteries in telephone exchanges, a non-automatic, type AT rectifier is made by the Westinghouse Company. The automatic device can be omitted where battery-charging outfits are to be used upon circuits where the supply is rarely or never interrupted, or where, as in telephone exchanges, an attendant is always present to restart the apparatus by hand when it is necessary to do so. To eliminate the noise due to current pulsations from interfering with the use of telephones connected to a battery while being charged, a damping or choke coil is usually sufficient for ordinary working conditions, but an additional damping coil is supplied where conditions require it. Furthermore, a two-winding transformer is supplied instead of an autotransformer to prevent the grounding of the telephone circuit should there be a ground on the alternating-current line, thereby preventing its interference with the operation of the telephones. Telephone batteries require approximately a constant rate of charge, and this type of rectifier is built with this point in view; that is, it is designed to be comparatively independent of voltage variations and to maintain approximately the same amount of current for which it is set throughout the charge.

27. Efficiency of Mercury Converter.—The efficiency of a mercury converter remains practically the same on the lowest running current as for full-load current, which is not true of a motor generator; hence, the average efficiency of the rectifier is said by its maker to exceed greatly that of a motor generator. The efficiency of a mercury converter varies with the voltage of the load; at maximum voltage of the converter, it is over 80 per cent., while at lower voltages it is not greatly decreased. The average life of a bulb under normal operating conditions is said by the makers to be upwards of 500 hours. This type of rectifier is made to operate on 110- and 220-volt alternating-current circuits and in capacities of 30 and 50 amperes for charging storage batteries of from 10 to 20 cells.

GENERAL ELECTRIC MERCURY-ARC RECTIFIER

28. Starting With Storage Battery.—A simplified diagram of connections of the mercury-arc rectifier made by the General Electric Company is shown in Fig. 16. The connections for starting the rectifier are shown in (*a*), in which dotted and dash lines represent circuits that are then open and need not now be considered. The same switches are shown and the various parts lettered as far as practicable as in the more complete and actual diagram of connections shown in Fig. 17. The rectifier is started by slightly tilting the tube, which causes the mercury in the starting-anode c to join that in the cathode b, thereby allowing current to flow through the circuit $j-w-d'-$ starting-anode resistance $l-$ starting anode $c-$ cathode $b-d-$ pilot lamp i and starting resistance k (which are in parallel) $-$ $j'-$ back to the battery. The arrows show the direction and path of this current. The breaking of the mercury stream on the righting of the tube causes an arc to be formed between the electrodes c and b. The alternating current then starts to flow through the circuit $g-a-b-d-$ pilot lamp i and resistance k in parallel $-y-g'$, as shown by the full wavy arrows, and through the circuit $g'-a'-b-d-$ pilot lamp i and resistance k in parallel $-y-g$, as shown by the dotted wavy arrows.

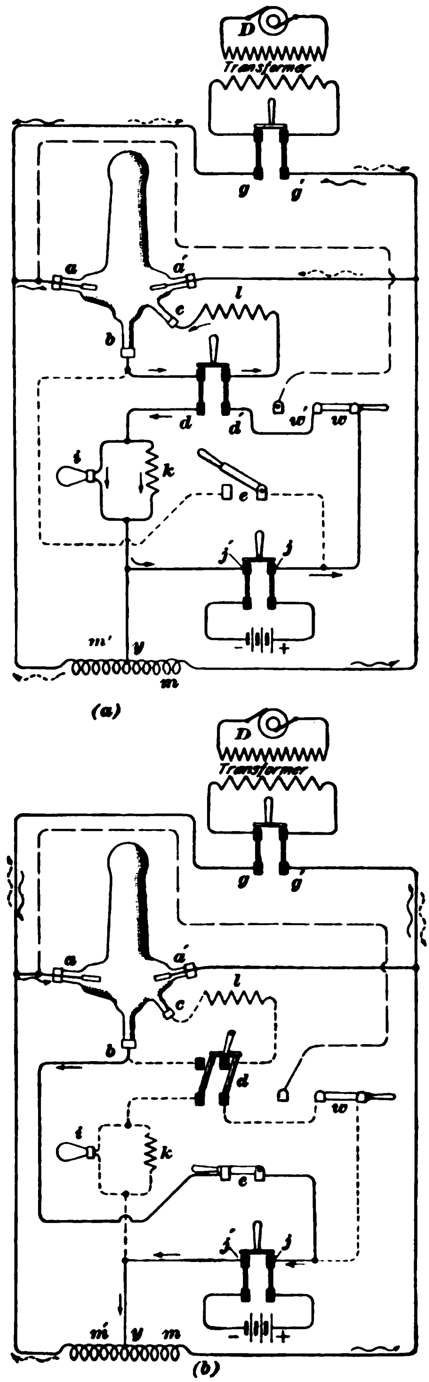


FIG. 16

The current through the tube soon warms it, after which the so-called *load switch* e is closed. Two paths are now available for the alternating current. It may flow from either anode a or a' through $b-d-i$ and k in parallel to y and also through $b-e-j-$ battery $-j'-y$. When the rectifier is operating properly, the switch d is opened, thereby giving the circuit shown by the full lines in (b), the circuits shown by dotted lines being now open at the switch d. The pilot lamp i is now dark. The starting resistance k prevents the current from rising to an excessive strength and the drop across this resistance allows the pilot lamp to light until the starting switch d is opened.

29. The source of alternating current is an alternator D, which supplies the rectifier with current through an ordinary transformer that steps the line or alternator voltage, which may be 1,000 or more volts, down to 220 or 110 volts. When the terminal g of the supply transformer is positive, the anode a is positive and current flows through $g-a-b-e-j-$ battery $-j'-y-m-g'$, as shown by the solid wavy arrows in Fig. 16 (b). As the potential falls below a value sufficient to maintain the arc, the inductive resistance m, whose inductance has been opposing the increasing current, and storing up energy in its magnetic field, produces a current that discharges through $a'-b-e-j-$ battery $-j'-y$. It thus maintains the arc while the supply alternating electromotive force passes through zero, reverses and builds up in the opposite direction to such a value as to cause the anode a' to have a sufficiently positive value to maintain the arc between it and the cathode b and cause a current impulse to pass through $g'-a'-b-e-j-$ battery $-j'-y-m'-g$, as shown by the dotted wavy arrows. The inductive resistance m' is now charging and a moment later, as this alternating impulse decreases in potential, discharges through $a-b-e-j-$ battery $-j'-y$ and maintains the arc until the alternating current again reverses and flows through $g-a-b-e-j-$ battery $-j'-m-g'$.

30. Starting With Dead Load.—When the rectifier is used for operating lamps or some other kind of a dead load,

no storage battery may be available for starting purposes. In such a case, the switch w will be closed in the position w', Fig. 16 (a), thereby allowing the tube to be started with alternating current. The load, whatever it may be, will occupy the position now held by the storage battery. The rectifier is started in the same way as before, but in this case the starting current is alternating and flows through $g - w' - d' - l - c - b - d - i$ and k in parallel $- y - m - g'$.

31. Complete Diagram of Connections.—A diagram of connections of the mercury-arc rectifier as actually used is

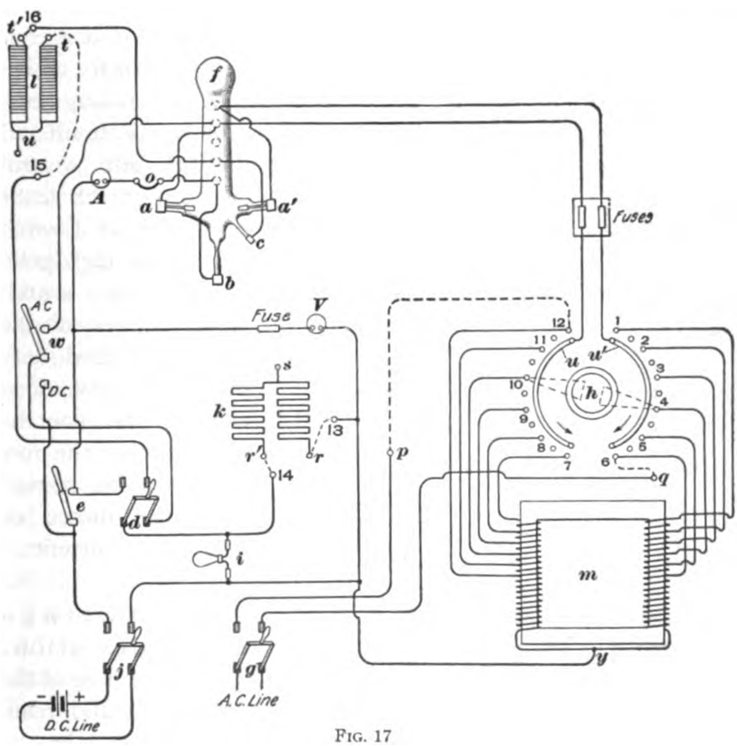


FIG. 17

shown in Fig. 17. Here o is a circuit-breaker or cut-out; A, the direct-current ammeter; V, the direct-current voltmeter; d, the starting switch; e, the load switch; f, the tube; g, the alternating-current circuit switch; i, the pilot lamp, which

TABLE III

CONNECTIONS FOR VOLTAGE TRANSFORMATIONS

Direct-Current Voltage	Connections for Starting Resistance	Connections for Starting Anode Resistance	Reactance for 220-Volt Alternating Current	Reactance for 110-Volt Alternating Current
80 to 120	13 to r and 14 to r'	15 to t and 16 to t'	q to 6 and p to 12	
46 to 80	13 to s and 14 to r'	15 to u and 16 to t'	q to 1 and p to 7	
30 to 46	13 to s and 14 to r r'	15 to u and 16 to t t'		q to 6 and p to 12
16 to 30	13 to s and 14 to r r'	15 to u and 16 to t t'		q to 1 and p to 7

serves as a signal to warn the operator when to open the starting switch; *j*, the direct-current circuit switch; *l*, the starting-anode resistance; *k*, the starting resistance, which is in parallel with the pilot lamp *i*; *m*, a compensating reactance that is connected directly across the alternating-current supply circuit and divided into several sections with leads running to a dial switch *h*; and *w*, a single-pole, double-throw switch on the back of the panel and used only when it is desired to change the connections so that the rectifier can be started on either direct or alternating current.

32. Voltage Transformation. The connections of the resistances and reactances depend on the direct-current voltage desired and the alternating-current voltage available; the

connections are as given in Table III. It will be noticed that for the higher direct-current voltages the two halves of both the starting resistance and the starting-anode resistance are connected in series, and for the lower voltages, but one-half of each is used or the two halves are connected in parallel. Assuming that 44 storage-battery cells requiring approximately 2 volts each, or a total of about 88 volts, are to be charged by such rectifier operating on 220 volts alternating current, the connections will be as given in the table, namely *13* to r, *14* to r', *15* to t, *16* to t', q to *6*, and p to *12*, as shown by dotted connections in Fig. 17.

33. Starting the Rectifier.—The single-pole, double-throw switch w, Fig. 17, on the back of the board is closed in the direct-current position $D\,C$ and allowed to remain there as long as the rectifier is used for charging storage batteries. With this switch closed in the direct-current position, the rectifier is started by closing the circuit-breaker o, the starting switch d, and the circuit switches g and j and giving the tube a slight shake, thereby connecting the electrodes b and c together by means of the mercury. Current then flows from the positive terminal of the battery through switches j, w and d – *15* – starting anode resistance l – *16* – anode c – mercury arc – cathode b – circuit-breaker o – ammeter A – switch d – $\left\{\begin{array}{c}\text{pilot lamp } i \\ \textit{14} - \text{starting resistance } k - \textit{13}\end{array}\right\}$ – switch j – negative terminal of the storage battery. As soon as the tube comes to rest, the mercury stream connecting the anode c to the cathode b breaks and the arc starts.

The current through the tube soon warms it and then the load switch e is closed, thereby connecting the positive terminal of the storage battery directly to the cathode b. If the rectifier voltage is lower than the battery voltage, the arc will go out at once because the current tends to flow from the battery to the cathode b and thence to one of the anodes a or a', but the arc will not carry current in that direction. If the arc goes out, switch g and then the switch e should be opened, the dial switch h moved one step counter-

clockwise, and the arc started as before. This process should be repeated until the arc continues to burn when the load switch is closed. As the dial switch *h* contains five steps and as the whole switch is capable of producing a change of 40 volts (120 to 80), each step causes a change of about 8 volts. If 88 volts are needed, the dial switch must be on the second step from the lowest position. This gives about 96 volts across the direct-current circuit—enough in excess of the battery voltage to force a charging current through the battery.

34. As soon as the rectifier is operating properly, the starting switch *d* should be opened, thereby cutting out the starting resistance *k* and the pilot lamp *i*, which then goes out, and also opening the circuit containing the starting-anode resistance *l*. When the rectifier is operating properly on alternating current, the path of the current may be traced as follows: Assuming an instant when point *p* in the alternating-current circuit is positive, current flows through *p* – *12* – two sections of the reactance coil *m* to *10* – contact arm on dial switch *h* – circular ring *u* – anode *a* – arc to cathode *b* – circuit-breaker *o* – ammeter *A* – load switch *e* – direct-current line switch *j* – positive terminal of battery – negative terminal of battery – direct-current circuit switch *j* – middle, or neutral, point *y* of the compensating reactance *m* – one portion of the reactance to the point *6* – *q* – other side of alternating-current circuit. During the next half cycle, the direction of the alternating current through the reactance is reversed and it flows from anode *a'* to cathode *b*, otherwise the circuit is similar to that just traced. The current always flows from one or the other of the two anodes *a* and *a'* to cathode *b* and through the battery as a direct current back to the middle point *y* of the reactance coil.

35. Regulating Strength of Direct Current.—The strength of the direct current can be regulated by turning the dial switch. For example, turning the switch until the arm rests on contacts *3* and *9* instead of *4* and *10* will raise the voltage in the direct-current circuit about 8 volts and thus increase the current proportionately. Until a person is thoroughly

familiar with the operation of the rectifier, it is best to place the dial switch on the lowest-reading points, that is, on *6* and *12*, when starting. When the required voltage and current are known and the action of the rectifier well understood, the dial switch can be placed on the proper points before trying to start.

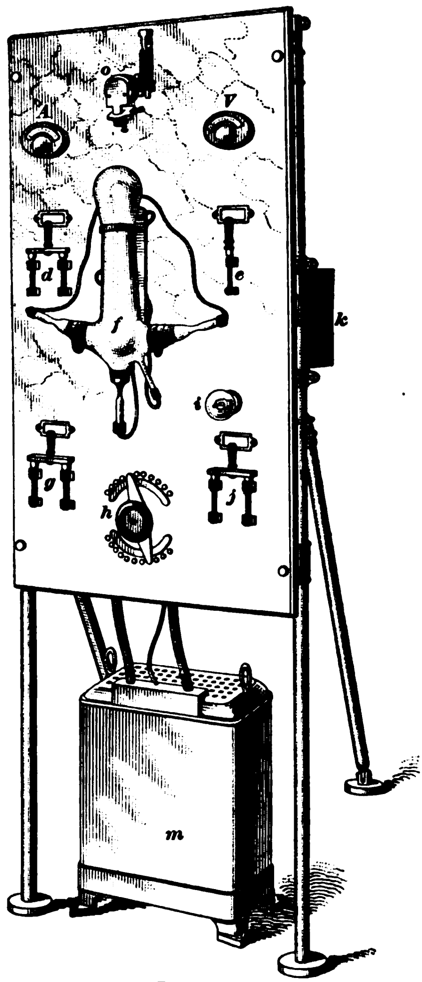


FIG. 18

When starting the rectifier on a load other than storage batteries, the switch *w* is closed in the alternating-current position *A C*. The process of starting is similar to that described.

36. Panel.—As built for commercial use, the General Electric mercury-arc rectifier consists of a panel, tube, holder, and compensating reactances. In Fig. 18 is shown the panel for a 30-ampere, 115-volt, single-phase rectifier with the various devices assembled thereon. As far as practical the same reference letters are used as in Fig. 17. This panel occupies a floor space of 24 inches by 18 inches; and when mounted on its frame, the top of the panel stands 76 inches above the floor. On the front of the board are mounted a circuit-breaker *o*, a direct-current ammeter *A*, a direct-current

voltmeter *V*, a starting switch *d*, a load switch *e*, a tube *f* and its holder, an alternating-current line switch *g*, a dial switch *h* for adjusting the reactance coil, which is contained in the case *m*, a pilot lamp *i*, and a direct-current switch *j*.

The reactance *m* may be mounted on the back of the panel or it may stand on the floor underneath as shown in Fig. 18. Special reactances for smoothing out nearly all the direct-current pulsations are furnished with rectifiers for telephone and telegraph work.

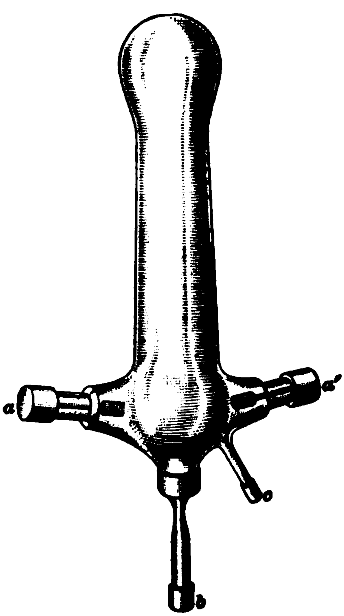


Fig. 19

On the back of the panel is mounted the single-pole, double-throw switch for changing connections so that the rectifier can be started on either direct or alternating current, also the starting-anode resistance and fuses for protecting the circuits. The starting resistance *k* is mounted on one of the pipe supports for the panel.

37. The **tube,** which is an exhausted glass vessel, is shown in Fig. 19. It has two anodes, to which connections are made through the metal caps *a* and *a'*; a cathode is connected to cap *b*; and a starting anode is connected to cap *c*.

The **tube holder** consists of a supporting frame so arranged that the tube may be tipped sidewise, but it returns to its normal position when released. Terminals mounted on the panel are connected by flexible wires with the tube electrodes.

38. Rectifier Connections.—If the rectifier is used for charging storage batteries, the polarity of the connections must be correct before the apparatus is started, else the tube may be ruined. The panel must be kept in an upright position in order that the mercury may remain in the two lower electrodes.

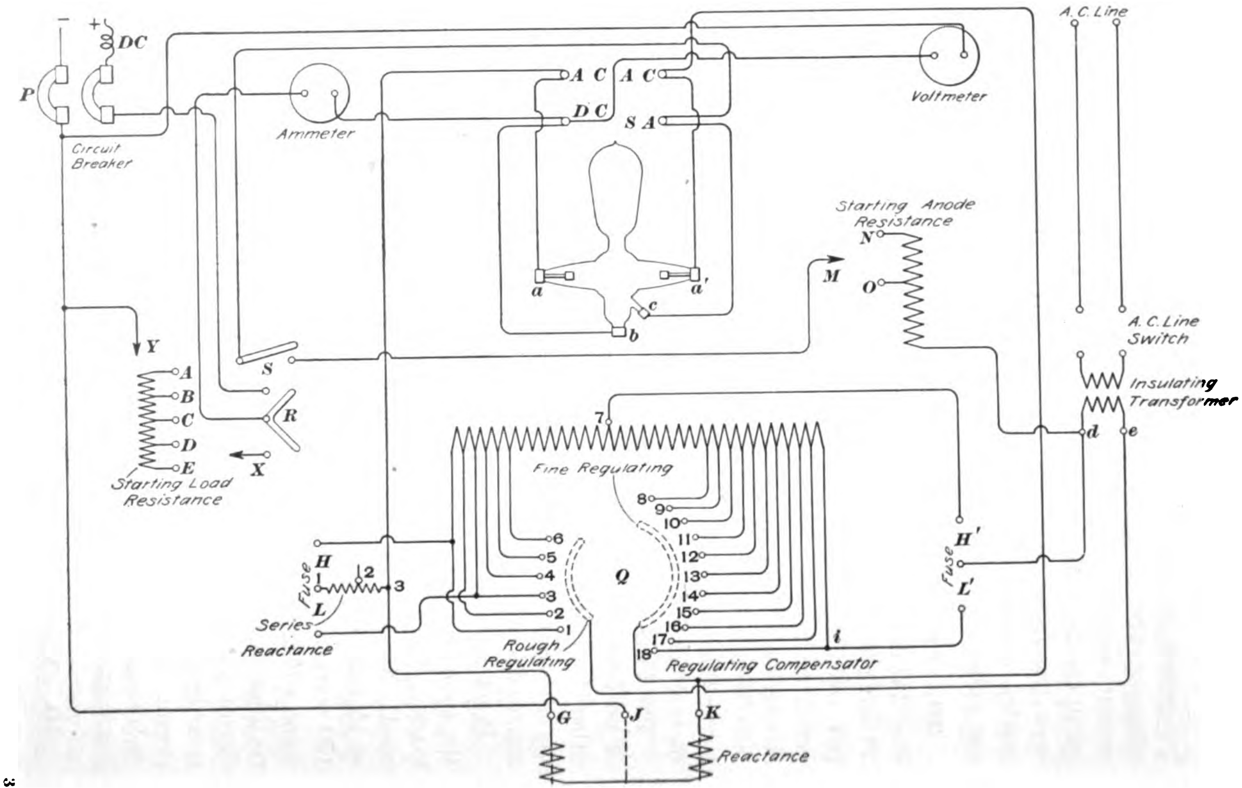
The tube must be handled very carefully and the seals must not be broken or damaged when installing or connecting. When stopping the charging of a battery, the alternating-current circuit switch should be opened first. On another type of rectifier, the tube is placed on the back of the panel, where it is less liable to injury and a handle attached to the tube holder extends through the board to the front for tilting the tube.

39. Efficiency of Rectifiers.—The rectifying devices thus far described are for direct-current outputs not exceeding 30 amperes at not over 120 volts, the alternating voltage being not over 220 volts. Such converters have been developed primarily to meet the demand for simple and easily operated storage-battery charging sets. Tubes for larger direct currents have been built, but they are not very extensively used. The larger the current output, the larger must be the tube. Experimental tubes have been built for as high as 100 amperes.

The General Electric rectifiers are designed for a frequency of 60 cycles, but they will operate practically as well on any other frequency from 60 to 140. The Cooper-Hewitt converters were also made to operate satisfactorily over a wide range of frequency.

Practically 15 volts is required to force the current through the tubes in commercial use for charging storage batteries at all loads. The efficiency must, therefore, depend on the voltage used. For example, if the rectifier is delivering 80 volts, a loss of 15 volts in the tube is $18\frac{3}{4}$ per cent., while if it is delivering 120 volts, a loss of 15 volts is only $12\frac{1}{2}$ per cent. As there are some additional losses, tests on the General Electric 30-ampere rectifier operating on a 220-volt, 60-cycle, alternating-current circuit showed the efficiency to be over 75 per cent. from one-quarter to full load when giving 80 volts in the direct-current circuit, and over 80 per cent. when giving 112 volts in the direct-current circuit. The efficiency is very nearly as high at one-quarter load as at full load.

40. Voltage Regulation.—The regulation of voltage from maximum to minimum current was approximately 7 per cent.;



DC
P
Circuit Breaker
Ammeter
A C
D C
A C
S A
Voltmeter
A. C. Line
Starting Anode Resistance
N
O
M
a
a'
b
c
Y
A
B
C
D
E
S
R
X
Starting Load Resistance
A. C. Line Switch
Insulating Transformer
d
e
7
Fine Regulating
8
9
10
11
12
13
14
15
16
17
18
6
5
4
3
2
1
Q
H
L
Fuse
Series Reactance
H'
L'
Fuse
Rough Regulating
Regulating Compensator
i
G
J
K
Reactance

Fig. 20

that is, as the current fell from its highest to its lowest value, the voltage rose about 7 per cent. of the value of the voltage when the maximum current was flowing. This is a good condition for storage-battery charging because the counter electromotive force of a battery rises as the charging proceeds and this tends to reduce the current; but as the current tends to decrease, the voltage of the rectifier increases and thus the two conditions tend to balance each other. The power factor of the rectifier during the efficiency test referred to averaged about 90 per cent.

The alternating electromotive force that can be rectified is practically unlimited. Doctor Steinmetz has stated that it is not probable that any of the high voltages now coming into use for power or lighting purposes will exceed the capacity of a properly designed rectifier with a good vacuum. A small current has been rectified with an alternating difference of potential of 36,000 volts applied to the rectifier terminals. Numerous tests have been made with an alternating difference of potential of 24,000 to 25,000 volts, giving about 60 kilowatts at 10,000 volts in the direct-current circuit with a tube slightly larger than can easily be put in a coat pocket. Rectifiers have been regularly used to supply direct current for arc lighting on streets, giving 6.6 amperes at 2,000 volts.

41. Single-Phase Mercury-Arc Rectifier.—In Fig. 20 are shown the circuits of a mercury-arc rectifier, made by the General Electric Company, that is especially applicable for charging storage batteries in telegraph and telephone stations. The maximum direct-current capacity of a single rectifier tube is 40 amperes. The main principles are the same as for the rectifier just described.

A front view of this rectifier is shown in Fig. 21. This shows that the tube is mounted upon the back of the panel and is tipped by the handle z; the switches and other instruments are placed upon the front of the panel. The regulating compensator is mounted upon the rear of the panel behind the hand wheels that control it. The reactance is in a case J placed on the floor.

As a rectifier will start better when there is no counter electromotive force in the load, an ordinary resistance, called the *starting load resistance*, is used as a load in starting. After having been started the rectifier adapts itself to any sort of a load. A pair of fuses are placed across the gaps H and H' for high direct-current voltages and across gaps L and L' for lower direct-current voltages. When the starting switch R is closed in the lower position, a spring closes the starting-anode switch S. But when the starting switch R is released, the upper blade strikes a fiber piece connected to the starting-anode switch S, thereby opening the starting-anode switch S at the same time that the starting switch R closes in the upper position.

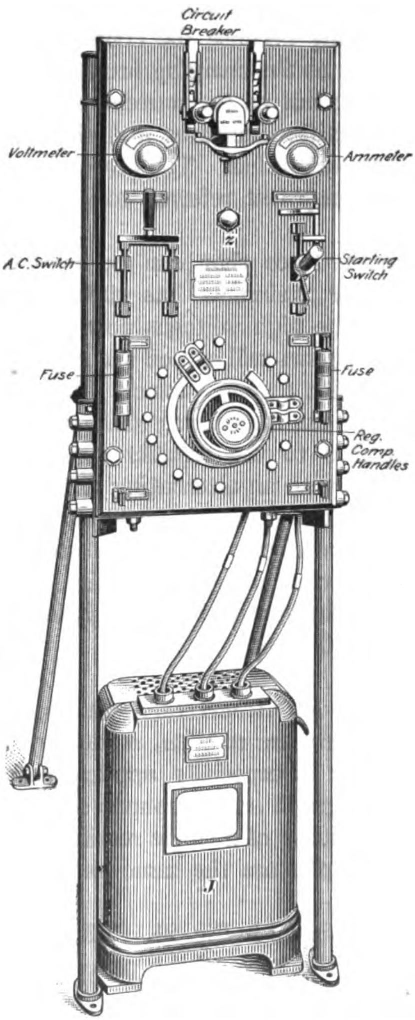


Fig. 21

42. Operation of Single-Phase Rectifier. After all the connections have been properly made, as shown in Fig. 20, the fuses and the single-regulating dial Q should be placed in their proper positions. Table IV gives the correct positions of the various parts, to obtain the various direct-current voltages, when the rectifier is operated on a 110-volt, 60-cycle

TABLE IV

CONNECTIONS WHEN OPERATED ON 110-VOLT, 60-CYCLE CIRCUIT

Direct-Current Volts	Position of Fuses	Position on Rough Dial	Connections of Series-Reactance Taps	Connections of Starting-Load Resistance	
5 - 15	$L-L'$	1	1 - 3	Y to A	X to B
10 - 22	$L-L'$	2	1 - 3	Y to B	X to C
15 - 30	$L-L'$	3 or 4	1 - 3	Y to A	X to C
20 - 40	$L-L'$	5 or 6	1 - 3	Y to C	X to D
30 - 40	$H-H'$	1	1 - 3	Y to C	X to D
42 - 55	$H-H'$	2	1 - 3	Y to B	X to D
54 - 74	$H-H'$	3	1 - 3	Y to A	X to D
66 - 110	$H-H'$	4, 5, or 6	1 - 3	Y to D	X to E

circuit and contact *M* is connected to contact *o* of the starting-anode resistance. Table V gives the correct positions when the rectifier is operated on a 220-volt, 60-cycle circuit and contact *M* is connected to contact *N* on the starting-anode resistance.

TABLE V

CONNECTIONS WHEN OPERATED ON 220-VOLT, 60-CYCLE CIRCUIT

Direct-Current Volts	Position of Fuses	Position on Rough Dial	Connections of Series-Reactance Taps	Connections of Starting-Load Resistance	
30 - 64	$L-L'$	1 or 2	1 - 3	Y to B	X to D
47 - 85	$L-L'$	3 or 4	1 - 3	Y to A	X to D
60 - 100	$L-L'$	5 or 6	1 - 3	Y to D	X to E
87 - 117	$H-H'$	1	1 - 3	Y to D	X to E
110 - 148	$H-H'$	2	1 - 3	Y to C	X to E
135 - 179	$H-H'$	3 or 4	1 - 3	Y to A	X to E

When the fuses and the dial Q are in position, the alternating-current line switch and the circuit-breaker P are closed. Then as the starting switch R is held in the lower position, the tube is gently rocked by means of the hand wheel z, Fig. 21. This causes a mercury bridge to be formed and broken between the starting-anode c and the cathode b, Fig. 20. Under ordinary conditions the formation of a single flash should be sufficient to start the rectifier, but in cold weather, or when a tube is run at lower than its rated voltage, it may be necessary to rock it more than once. In cold weather the switch should be held in its starting position for at least 30 seconds, so that the tube will be warmed somewhat before full load is thrown on.

43. When starting the rectifier current flows from one side d, Fig. 20, of the alternating-current line through the starting-anode resistance – switch S – starting anode c – cathode b – ammeter – switch R – X – starting load resistance – Y – J – G – series-reactance – L (or H) – one of rough-regulating contacts to the other alternating-current line e.

When the hand is removed, the starting switch R will automatically close in the upper position, thereby transferring the rectified current from the starting-load resistance to the positive wire of the load, and also opening the starting-anode circuit at S. Current then flows from d through H' – 7 (or through L' – i) – some contact on fine-regulating side of the regulating compensator – anode a' – cathode b – ammeter – switch R – positive terminal – direct-current load – negative terminal – J – half of the reactance – G – series-reactance – H (or L) – rough-regulating side of regulating compensator to e; or from e through the rough regulation – H (or L) – series-reactance – anode a – cathode b – ammeter – switch R – load – J – K – fine regulation – H' (or L') – d. At each reversal the reactances discharge and maintain the arc until the voltage reaches the value required to maintain the current against the counter electromotive force of the battery. The reactances also reduce the fluctuations in the direct current.

44. If the load is a battery and its voltage is higher than that of the rectifier, the arc in the tube will go out when the

starting switch moves to the load position. If such is the case, the voltage of the rectifier should be raised by means of the fine regulating-compensator switch, which should be moved down, or counter-clockwise (looking at the front of the rectifier panel), and the tube restarted. In case this does not give the desired current, the voltage should be further increased by means of the rough-regulating compensator switch, which should be moved up, or counter-clockwise, until the desired current and voltage is obtained. After once determining the position of the rough-regulating switch, most of the regulation can be secured by means of the fine-regulating switch. Any number of similar rectifiers may be operated in parallel; hence, large current capacity may be thus obtained.

45. Rectifier Tube.—The General Electric Company makes different tubes, which vary in size according to the ampere capacity and in shape according to the direct-current voltage at which they are rated. A tube should never be used to deliver current at a higher voltage than that for which it is rated. If used to deliver current at lower than the rated voltage, the tube may sometimes be hard to start, but otherwise it will be satisfactory. The anode electrodes are made of graphite. The quality of the vacuum may be estimated by noting the sound the mercury makes when allowed to roll gently about in the upper part of the tube. If it makes a clear metallic click, the vacuum is good; but if the sound is dull and the mercury sluggish in moving, the vacuum is poor and the life of the tube may be short, or it may not start at all. The tube is placed in its holder by inserting the small part of the tube, just above the anode arms, in the upper clip, then gently lowering it until it rests firmly on the lower support.

46. Switches.—The circuit-breaker is of the double-pole overload type and should be so set that it will open the load circuit at any desired current value that does not exceed the rated ampere capacity of the tube. The circuit-breaker is not, of course, a protection against the overcharging of a battery caused by too long a charge, but it is a protection, if properly set, against sending too large a current through the battery

or other load if this is less than the rated capacity of the tube, or against taking excessive current from the rectifier. If the current falls below what is required to maintain the operation of the tube, the arc in the latter will break and form an open circuit through which the batteries cannot discharge. The tube itself, therefore, forms an underload circuit-breaker. The regulating compensator, or dial switch, is controlled by two concentric hand wheels, the large one for rough regulation and the smaller one for finer regulation.

47. Fuses.—The two fuses, when placed in the upper two clips, enable a higher range of direct current to be obtained than when placed in the lower two clips. The fuses should be placed as directed in Tables IV and V. They prevent an excessive current in the alternating-current side of the circuit and therefore protect not only the rectifier devices but also the alternating-current lines and transformers in case of short circuits.

48. Resistances.—The starting-load resistance is composed of four resistance tubes, arranged in one unit with five terminals A, B, C, D, and E, Fig. 20, to any two of which the flexible cords Y and X should be connected as directed in Tables IV and V.

The starting-anode resistance consists of one resistance tube with a tap brought out at the middle. The flexible cord M should be connected to N or O, as directed in the tables.

49. Reactances.—Between the fuse terminal *1* and the point *3*, there is a series, or direct-current, reactance which is mounted on the pipe supports back of the panel. It has three terminals but only two, *1* and *3*, are used in this type. The function of this direct-current reactance is to smooth out the slight pulsations in the wave form of the rectified current so that they will not cause humming in a telephone, current for which is supplied by the storage battery in the telephone exchange. It is claimed that the noises in the receiver are thereby sufficiently eliminated to satisfy the most exacting telephone engineer. The impedance is 25 ohms at 60 cycles.

When a telephone exchange has two batteries, one to be charged while the other is feeding the line circuits, the direct-current reactance is not required.

50. Insulating Transformer.—It is a common practice for central electric-light or power stations to ground the center of the secondary winding, called the *neutral point*, of line transformers, and it is also customary to ground the positive terminals of the batteries of common-battery telephone systems. If the secondary of such a line transformer is connected directly to the rectifier, a short circuit will be formed through the rectifier tube as soon as the mercury arc is started. It has therefore been found necessary to eliminate this trouble by inserting what is termed an *insulating transformer* between the secondary of the line transformer and the rectifier. The insulating transformer is made like ordinary transformers, except that it is usually designed to give about the same voltage across the secondary as across the primary and the secondary is not grounded.

51. Efficiency.—The efficiency of the single-phase rectifier at 30 volts direct current is stated by the makers to be about 60 per cent. regardless of its ampere capacity. When charging 17 cells of battery, the efficiency is stated to be about 65 per cent.; and when charging 40 cells or more, the efficiency will increase to about 80 per cent.

POWER EQUIPMENT

(PART 4)

SOURCES OF TELEGRAPH CURRENTS

DYNAMOS IN TELEGRAPH OFFICES

ADVANTAGES OF DYNAMOS

1. Dynamos and storage batteries are rapidly replacing primary batteries, especially in large telegraph offices, being preferable for many reasons. The first and greatest advantage lies in the fact that they are much more economical; one dynamo can replace a very large number of primary cells. The dynamos installed in 1880 in the New York Western Union office replaced 12,000 primary cells, and the new plant, put in after the fire in 1890, displaced all primary cells. Besides doing work that would have required 22,000 cells, the dynamos saved considerable space for the 10,000 cells in use previous to 1890 required nearly one entire floor. Furthermore, primary cells must be periodically replenished, and require continual inspection and attention in order to keep their electromotive force even approximately constant. In addition not over three or four telegraph circuits can be successfully worked from the same set of cells, so that a large number of separate batteries are required in a main office where a large number of wires terminate. On the other hand, dynamos and even storage cells require less attention, and one dynamo or storage battery will supply all circuits needing about the same voltage.

2. Another advantage of dynamos, converters, and storage batteries over primary cells is that the operation of one of several telegraph instruments, if all are connected to any one of the first three-mentioned sources of current, will affect the current strength in the other instruments less than would be the case were the several lines supplied by only one set of gravity cells.

Suppose, for instance, that three telegraph lines are to be supplied with current at 70 volts, each line requiring 25 milliamperes, or 75 milliamperes in all. This will require, approximately, 70 gravity cells connected in one series set. The internal resistance of this battery, assuming 2 ohms per cell, will be 140 ohms. The resistance of each circuit, including the telegraph relays, may be taken as 2,380 ohms. Now, when all three telegraph keys are closed, the current in each will be 25 milliamperes. For the total current will be $\frac{70}{140+\frac{2380}{3}}$ $=.075$ and one-third of .075 is .025, that is, 25 milliamperes in each line. Now, when only one key is closed, the other two operators having their keys open in the act of making spaces, the current in the one closed line will be $\frac{70}{140+2{,}380}=.0277$. Thus, the current in one line varies from .025 to .0277, or over 10 per cent.

If a dynamo or storage battery is used, the internal resistance will be so very small in either case that it can be entirely neglected, giving practically the same current in each line, no matter whether one or all three keys are closed. Of course, the current may not remain uniform if the machine or storage battery is excessively overloaded and a large number of the circuits are opend or closed at the same instant.

3. Relative Cost of Operation.—It is generally most economical to use dynamos as a source of current supply. Next in order of economy come converters, motor-dynamos, storage batteries, and, finally, primary cells. Mr. Preece, formerly head of the telegraph and telephone systems of the British Government, stated, that for telegraph and telephone

purposes, electricity produced by primary batteries cost $1.50 per kilowatt-hour, as against 2 cents by the system, in which dynamos and storage cells were used. The relative cost is as much in favor of the dynamo and storage battery in the United States as in England. The relative cost of operating sounders from electric-light mains and from primary cells will be shown later.

KIND OF DYNAMOS USED

4. Practically all dynamos, motor-dynamos, and converters now used in ordinary telegraph work are simple shunt machines. However, the fields of several may be excited by one dynamo, instead of each one supplying current for its own field. Electromotive forces varying by irregular jumps from 7 to about 375 and even 400 volts are now in use. At least as many dynamos are needed as there are different electromotive forces required.

Good engineering practice can be best treated by means of descriptions of prominent and successful plants installed by the large telegraph companies. The arrangement of apparatus and circuits on the telegraph-line side of converters and motor-dynamos will be exactly the same as for dynamos. Whatever is said concerning dynamo circuits will generally hold also for the telegraph-line side of motor-dynamos, converters, and storage batteries.

CURRENT SUPPLY FOR LOCAL CIRCUITS

SOUNDERS OPERATED BY DYNAMOS

5. There seems to be a tendency to increase the resistance of sounders that are to be operated by dynamos, or, at least, to increase the resistance of the sounder circuit. First, 4-ohm sounders and 1-volt dynamos were used; now 20-ohm sounders, each in series with a non-inductive resistance of 200 ohms across a 40-volt dynamo, and 25-ohm sounders in series with 25 ohms across a 7-volt machine are used. When an electric-light 110-volt circuit is used, 20-ohm sounders, each in series with a 1,100 ohm, non-inductive resistance are employed.

6. Fig. 1 shows how all the sounders in one office may be supplied with current from one dynamo. In the New York office of the Postal Telegraph Company, a 40-volt machine is used for this purpose. In series with each sounder, which has a resistance of 20 ohms, is connected a resistance coil *a* of 200 ohms. This resistance coil *a* is made of German silver or other high-resistance wire wound non-inductively on a hollow spool. Thus, each sounder circuit has a resistance of 220 ohms. This resistance across 40 volts will give about 180 milliamperes for each sounder, so that if there are 100 sounders, the maximum current

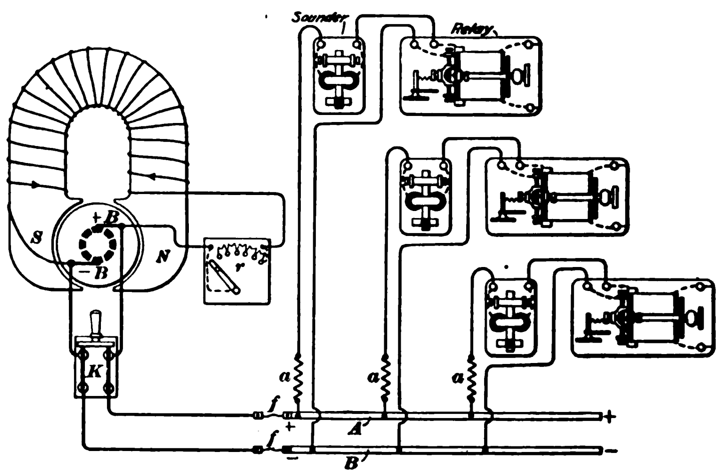


FIG. 1

the dynamo will be called on to furnish will be 18 amperes. Thus, to operate these 100 sounders will require a 720-watt or about a 1-horsepower machine. This arrangement is not very efficient, for only 64.8 out of the 720 watts are utilized in the sounders, the rest being consumed in heating the resistance coils *a*. However, this arrangement makes the sounders very quick-acting, for the time constant $\frac{L}{R}$ is much smaller than would be the case if the total resistance, 220 ohms, were all in the sounder coils. It is also much smaller than if the 20-ohm sounders were connected directly to a dynamo having an

electromotive force just high enough (3.6 volts) to send 180 milliamperes through them without any external resistance *a*. Furthermore, as the sounders are continually opening and closing the circuit, and so varying the total current output of the dynamo, a larger percentage variation would be produced in the voltage at the bus-bars in the case of the lower voltage system, which would perhaps cause the sounders to work with less uniformity.

The dynamo is connected through the double-pole switch *K* and the fuses *f* to the bus-bars *A* and *B*. In each separate circuit across the bus-bars *A* and *B* there is connected a sounder, the contact points of the relay that controls the sounder, and the resistance *a*. The non-inductive resistance coils *a* are located as near to the bus-bars as is convenient, but each sounder and its relay are placed upon tables distributed throughout the room.

7. In their main office in New York, the Western Union Telegraph Company used 25-ohm sounders each in series with a 25-ohm, non-inductive resistance connected across a 7-volt dynamo. This arrangement is the same as that shown in Fig. 1. It is a good plan to put a fuse in each sounder circuit. While the sounders take .14 ampere, the voltage is only 7, so that the total energy consumed is only (as in the preceding arrangement) about one-seventh as much. The repeating sounders of this company are wound to 20 ohms, and in series with each is inserted a non-inductive resistance of 20 ohms. Such an arrangement makes the sounder act more quickly, a very desirable feature for repeating sounders.

SOUNDERS SUPPLIED FROM ELECTRIC-LIGHT MAINS

8. For several years, a number of the Western Union Telegraph Company's branch offices were equipped with 20-ohm sounders in series with two 550-ohm, incandescent lamps, all connected across the 110-volt, direct-current, electric-light mains from central stations. This arrangement is shown in Fig. 2, in which *S* are the 20-ohm sounders, *R* the relays that control the sounders, and *l* the incandescent lamps, one in each end of each tap. The lamps not only act as visual telltale

signals in case of a cross or short circuit anywhere in the sounder circuit, but also, as the total resistance of each sounder circuit is 1,120 ohms, they keep the current down to about .1 ampere.

Assuming that a sounder will be closed 60 per cent. of the time, for 10 hours a day, and that the current at 110 volts costs $1\frac{1}{2}$ cents an ampere for each hour, which was the cost of current for lamps ($\frac{3}{4}$ cent for each 16-candlepower lamp an hour on a 110-volt circuit) in Boston in 1899, the cost of running one sounder for a day of 10 hours under this arrangement was $\frac{6}{10}\times\frac{110}{1,120}\times\frac{3}{2}\times 10 = .88$, or about $\frac{9}{10}$ cent per day of 10 hours. The chief fault with this arrangement was the breakage of

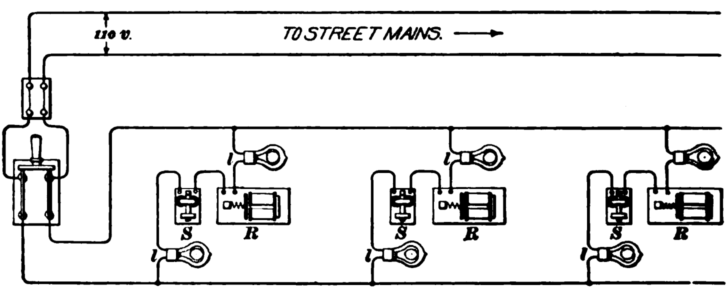


FIG. 2

filaments in the resistance lamps. The filaments burned out very easily when jarred or set into vibration.

9. The arrangement shown in Fig. 2 has been replaced by that shown in Fig. 3, which has proved so economical and satisfactory that it was introduced in all the telegraph offices of this company in the Boston district wherever the direct 110-volt light service was available. In this arrangement, a 200-ohm sounder in series with a 4,000 non-inductive resistance coil is connected across the 110-volt light circuit. In this case, S represents 200-ohm sounders, R the relays that control the sounders, and r the 4,000-ohm resistance coils, which are made of No. 32 German silver wire. The current in this case is $110 \div 4,200 = .026$ ampere. However, the number of

ampere turns is about the same in both cases. Making the same assumptions as in the preceding calculations, the cost is $\frac{6}{10}\times\frac{110}{4{,}200}\times\frac{3}{2}\times 10 = .23$ cent, or less than $\frac{1}{4}$ cent for the 10 hours. This is less than one-third what it cost for current under the preceding arrangement.

For 365 days, of 24 hours each, the current would cost only $2.01 per sounder, and if 10 per cent., the customary discount

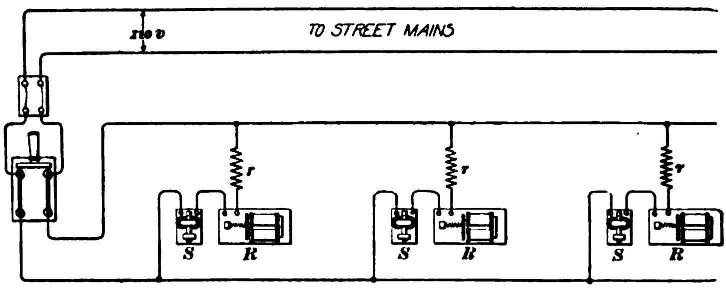


FIG. 3

allowed for prompt cash payment on small electric-light bills, is deducted, the cost is reduced to $1.81. This is less than the cost of maintaining two gravity cells, with the additional saving in attendance, trouble, dirt, and especially space, which item is very important in city branch offices, where space rents are high.

ARRANGEMENT OF DYNAMOS FOR MAIN-LINE CIRCUITS

WESTERN UNION ARRANGEMENT

10. **Definition of Terms.**—In the large New York office of the Western Union Telegraph Company, there were three similar sets of dynamos: one set supplied positive and another set negative currents to the main-line circuits, the third set being held in reserve to replace either of these sets should either become disabled from any cause. There were five machines in each main-line set.

A dynamo used in telegraphy is spoken of as furnishing *positive currents* or as having *positive potential* when the positive brush of the dynamo is connected to the line and its negative brush to the earth; that is, when the direction of the current is from one pole or brush of the dynamo out over the line wires and back through the earth to the other grounded pole or brush of the dynamo. Currents may be spoken of as being positive when the direction of the current is from some point under consideration out over the line, returning through the earth to the starting point. When the current flows into the ground, through the ground to the distant office, and returns through the line, it is spoken of as a *negative current* and the dynamo as having *negative potential* or *polarity*.

11. General Description.—Fig. 4 shows a main-office set of five main-line dynamos, No. *1*, No. *2*, No. *3*, No. *4*, and No. *5*, and also three machines that furnish currents at 7, 23, and 45 volts, respectively. Duplicate sets of these three dynamos are nearly always provided.

Besides these machines, there are thirty or more small dynamos used as intermediate main-line batteries. They deliver currents at from 50 to 125 volts, each machine having a lamp permanently connected in series with it. This lamp is to prevent injury to the dynamo in case of a short circuit. As each machine feeds only one wire, it normally supplies currents of only 30 or 40 milliamperes. These dynamos are simply small shunt machines, and as such machines have been considered, it is not necessary to illustrate or describe them here.

12. Main-Line Sets.—Each main-line set consists of five 40-ampere dynamos; one of these, No. *5*, is self-excited and the other four are separately excited from it. The armatures of the five dynamos in one set are connected in series. The first and second dynamos in each set generate current at a potential of 70 volts; the third and fourth, at 60 volts; and the fifth, at 65 volts. Therefore, the difference of potential between the ground and the various leads will be 70, 140, 200, 260, and 325 volts, as indicated at the bus-bars *B*.

9

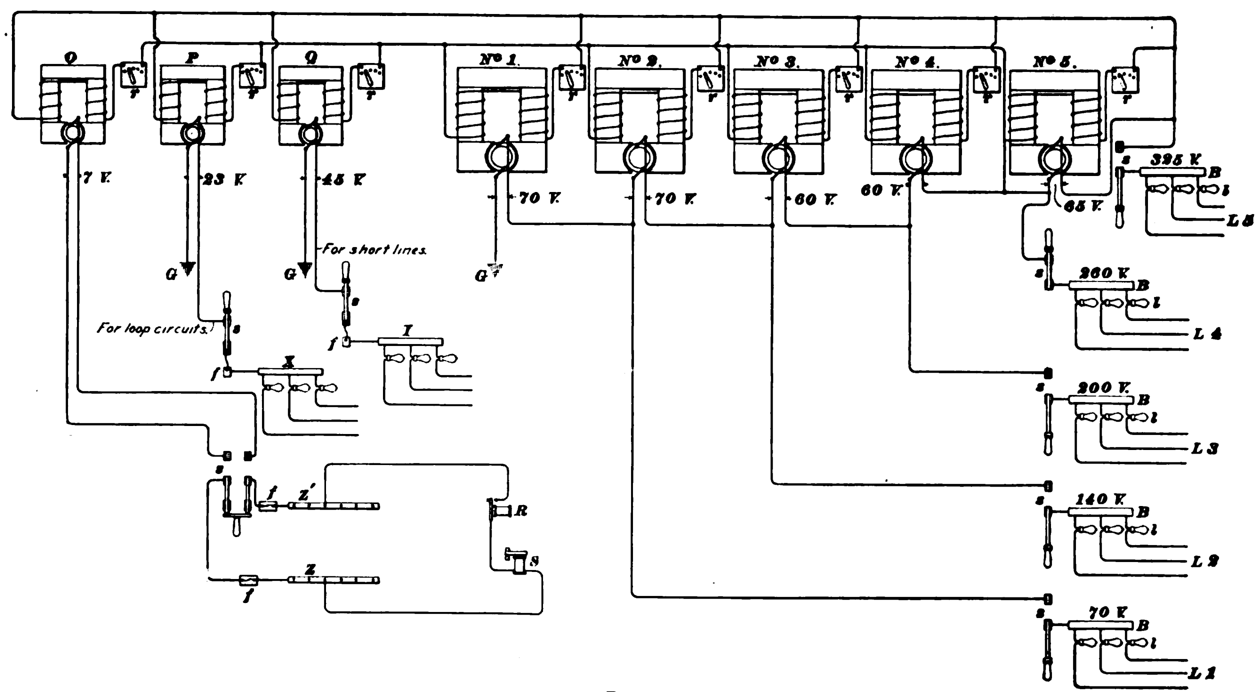

O
P
Q
No 1.
No 2.
No 3.
No 4.
No 5.
r
7 V.
23 V.
45 V.
70 V.
70 V.
60 V.
60 V.
65 V.
G
G
G
For short lines.
For loop circuits.
s
f
X
Y
Z'
Z
R
S
325 V.
260 V.
200 V.
140 V.
70 V.
B
l
L 5
L 4
L 3
L 2
L 1

Fig. 4

NOTE.—A bus-bar is usually a large copper wire or copper bar upon which are fastened or tapped a large number of wires. Thus, the currents from all the wires flow into this bus-bar, and from it to the dynamo, or vice versa, if the currents flow in the opposite direction.

Between the dynamos and the bus-bars, which are located above and behind the main-line switchboards, are knife-blade switches; these are located in a convenient place behind the switchboards, which are in the operating room, so that in case of fire all current can be quickly cut off from the whole board and room. There is also a knife switch (which is not shown) in the ground wire leading to the main-line switchboards, to be opened in case of fire. From the main-line bus-bars, a large number of wires are led through non-inductive resistances *l* of from 2 to 2½ ohms per volt. That is, the non-inductive resistance at 2 ohms per volt in each line circuit connected to the 70-volt bus-bar is about 140 ohms; to the 140-volt bus-bar. about 280 ohms; and so on. The Western Union Telegraph Company used incandescent lamps especially made for it for this purpose.

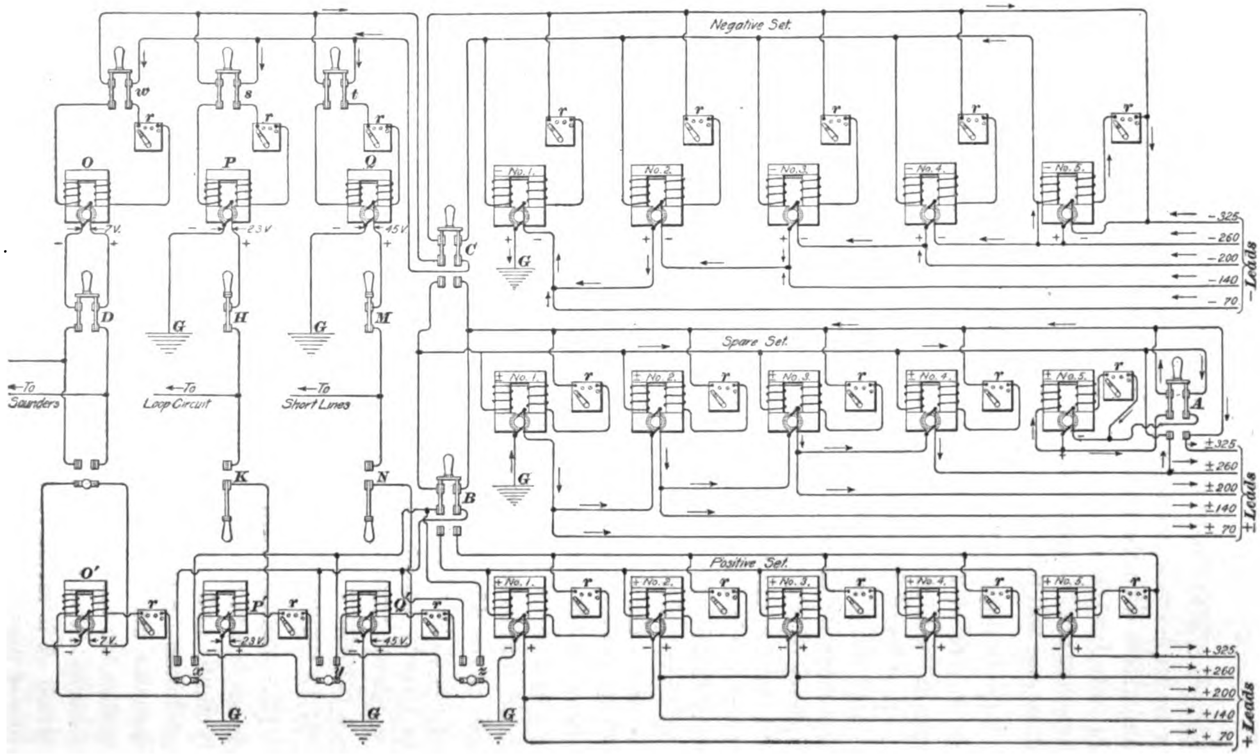
For the sake of simplicity, a main-line switchboard is not shown; *L 1*, *L 2*, *L 3*, *L 4*, and *L 5* represent groups of lines with a lamp in each line circuit. Although only three lines are shown in each group, nevertheless, hundreds of lines are supplied through the 70-, 140-, and 200-volt bus-bars alone.

13. Dynamos Unequally Loaded.—The current that goes out over the group of lines *L 1* comes only from dynamo No. *1*, but the current that passes through the group *L 2* passes through both dynamos No. *2* and No. *1*. Similarly, the current in group *L 3* passes through dynamos No. *3*, No. *2*, and No. *1*, and so on. Thus, No. *5* furnishes less current than any of the others. For instance, if 20 milliamperes are being used in each line, and there are 200 lines in each group, dynamo No. *5* will supply 4 amperes; No. *4*, 8 amperes; No. *3*, 12 amperes; No. *2*, 16 amperes; and No. *1*, 20 amperes. Thus, the dynamos are not equally loaded, that is, they are not doing the same amount of work. For a strictly economical arrangement under this assumption, dynamo No. *2* should be smaller than No. *1* in the proportion of about 16 to 20; No. *3* smaller than No. *1* in the

proportion of about 12 to 20, and so on. No. *5*, being used only for multiplex sets, would especially be doing but little work in comparison with the others. Consequently, it supplies current not only for the *L 5* group of circuits, but for the fields of all these five machines and also for the fields of three other dynamos whose use will now be explained.

14. Dynamo *O*, Fig. 4, is a 300-ampere machine supplying current at 7 volts for local Morse and repeating sounders, transmitters, and pole changers. Two wires, one from each bus-bar *Z* and *Z'*, are run to each desk set having such instruments. One sounder *S* controlled by the relay *R* is shown connected across the bus-bars *Z* and *Z'*. The dynamo *P* has a capacity of 80 amperes at 23 volts, and is used for special local and branch-office circuits, called *loop circuits*. The third dynamo *Q* is a 40-ampere, 45-volt dynamo for use on city and other short lines. There are two of each of these 7-volt, 23-volt, and 45-volt dynamos, but only one of each voltage is in use at one time, the others being held in reserve. One pole of each of the 23-volt and 45-volt dynamos is grounded. The other pole of the 23-volt machine is carried through a switch and fuse to a bus-bar *X* from which taps are taken to the loop switchboard, and to the various desk sets requiring this voltage. One pole of the 45-volt dynamo is carried to the city switchboard for use on short lines, such as city and local race-track circuits. As already stated, the fields of the eight dynamos are excited by current from the No. *5* dynamo. In each field circuit, there is a rheostat *r* by means of which the voltage of each dynamo may be regulated independently of all the others.

15. Description of Complete Main-Office Installation.—In Fig. 5 are shown three complete sets of main-line dynamos and also two sets of 7-volt, 23-volt, and 45-volt machines. A double-pole, double-throw switch *A* is connected in such a manner as to reverse the leads from machine ±No. *5*, so that the whole spare set may be made to furnish currents at either positive or negative potential. In order to do this, the switch *A* is arranged to reverse the current through the field coils of the first four machines and also to reverse the terminals



Negative Set.
Spare Set.
Positive Set.
To Saunders
To Loop Circuit
To Short Lines
-Leads
±Leads
+Leads
-325
-260
-200
-140
-70
±325
±260
±200
±140
±70
+325
+260
+200
+140
+70
7V.
23V
45V

FIG. 5

of dynamo ±No. *5* with respect to the ±325-volt and the ±260-volt leads. Thus, when the switch *A* is closed in the upper position, the potentials of all five machines are positive, and when the switch is closed in the lower position, they are all negative. The arrows show the direction of the current as a result of the switch *A* being closed in the upper position. By simply reversing the switch *A*, the ±leads may be made + or −.

16. The double-throw switches *B* and *C* have been added to this diagram to show how dynamo ±No. *5* in the spare set may be made to supply current for the fields of either auxiliary set *O*, *P*, and *Q* or *O'*, *P'*, and *Q'*. The negative and spare sets and the dynamos *O*, *P*, and *Q* are represented as in use. The spare set is furnishing positive current and is replacing the positive set while the latter is idle. The dynamo −No. *5* is supplying current for the fields of the negative set, and also for the fields of dynamos *O*, *P*, and *Q*. Should it be desirable to use the dynamos *O'*, *P'*, and *Q'* instead of the dynamos *O*, *P*, and *Q*, it is merely necessary to open the switch *C*, close the switch *B* in the upper position, as shown, and also close the switches *x*, *y*, and *z*, which are here shown open. The ±No. *5* dynamo will then furnish current in the proper direction for the fields of dynamos *O'*, *P'*, and *Q'*, and with switch *C* open, the fields of dynamos *O*, *P*, and *Q* are getting no current.

If the positive set is in use and the spare set idle, and it is desirable to use the dynamos *O'*, *P'*, and *Q'*, the switch *C* should be open on both sides and the switch *B* closed in the lower position. If the spare set were to be used in place of the regular negative set, and it were desirable to use the dynamos *O*, *P*, and *Q*, and not *O'*, *P'*, and *Q'*, the switch *A* would be closed in the lower position so that the spare set would be furnishing negative currents, the switch *C* would be closed in the lower position, and the switch *B* would be open. These two switches *B* and *C* are so connected that, no matter in which position they are closed, provided the switch *A* is closed on the proper side, the polarity of the 7-volt, 23-volt, and 45-volt machines is never reversed.

17. Substitution of Dynamos.—By means of the switches w, s, t, x, y, and z, Fig. 5, in the field circuits of the 7-volt, 23-volt, and 45-volt machines, it is possible to use any one, two, or three of these machines at one time. For instance, if it were desirable to use dynamos O, P', and Q', and the regular positive and negative sets were in use, switch B would be closed

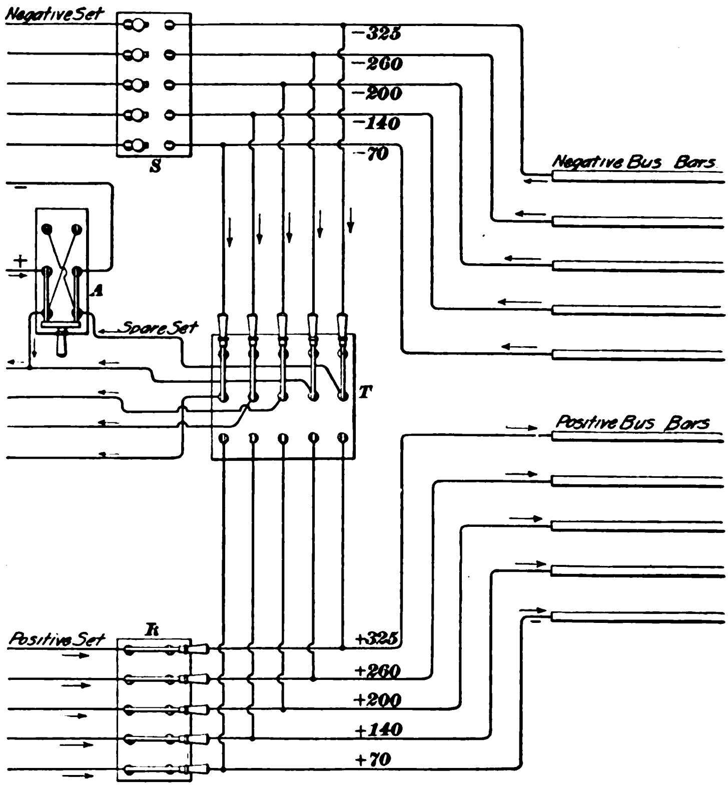


FIG. 6

in the lower position, switch C closed in the upper position, switches w, y, and z in the field circuits of dynamos O, P', and Q' would be closed, switches s, t, and x in the field circuits of dynamos O', P, and Q would be open, switches D, K, and N would be closed, and switches E, H, and M would be open. Switches D, E, H, K, M, and N are so arranged that dynamos

in one set can be connected with the leads to the operating room before the dynamos in the other set are cut off, thus avoiding even a momentary interruption of the current when changing over from dynamos in one set to those in the other set.

18. In Fig. 6 is shown an arrangement of knife-blade switches whereby the whole spare main-line set may be thrown in before the regular positive or negative set, which the spare set is to replace, is cut out, thus avoiding even a momentary interruption in the current supplied to the main-line circuits. Two of these rows, *R* and *S*, are single-throw knife switches; the third row *T* consists of double-throw knife switches. When both regular sets are in use and the spare set is not in use, all the single-throw switches *R* and *S* are closed and the double-throw switches *T* are open on both sides. If the spare set is to replace the regular negative set, switch *A*, which is the same as switch *A*, Fig. 5, is closed on the lower side and the double-throw switches *T* are all closed on the upper side before the single-throw switches *S* are opened. Thus, before the single-throw switches *S* are opened, the spare and negative sets are in multiple with each other, and both sets help to supply negative currents to the lines. In any case, before closing the double-throw switches *T*, the switch *A* must be closed on the proper side. The direction of the currents when the switch *A* is closed in the lower position is shown by the arrows in Fig. 6; when the switch is closed in the upper position, the currents from the spare set will flow in the opposite direction.

19. Connection of Bus-Bars to Switchboard.—A way to connect the bus-bars and disks on the line switchboards is shown in Fig. 7, which shows only a portion of a main-line switchboard. It will be noticed that each disk in the first or top horizontal row is connected through a lamp *l* to the 200-volt bus-bar. Each disk in the second and third rows is connected through a lamp *l* to the 140-volt bus-bar; and each disk in the fourth row, through a lamp *l* to the 70-volt bus-bar. Since many more wires are worked on the second potential (140 volts) than on either the first or third, the second has two rows of disks assigned to it, but one row is sufficient for each of the

other two potentials. Should any circuit containing one of the lamps and a dynamo become short-circuited, the lamp will glow, thus serving as a visible signal and calling the attention

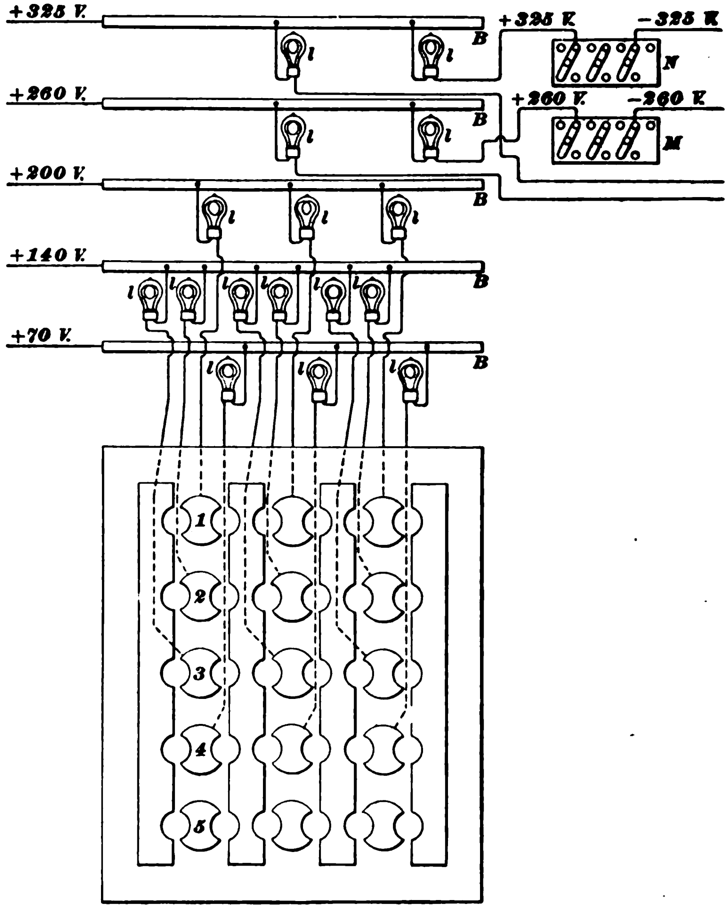


FIG. 7

of the chief operator to the fact that the disk or strap on the main-line switchboard directly below it is grounded.

In such a large office only dynamos of the same polarity are connected to any one switchboard. The dynamos of opposite polarity are connected to other boards. The two higher

potentials, that is, the 260- and 325-volt bus-bars, are not connected to the main-line switchboard. Because these two higher potential dynamos are used only for duplex and quadruplex circuits, their bus-bars are connected through lamps directly to the small switches *M* and *N* on the desks upon which are placed the duplex and quadruplex sets. To these desks it is necessary to bring both positive and negative currents of the same voltage.

SAFETY DEVICES

20. When gravity cells are used for telegraph purposes, fuses or other safety devices, to prevent the flow of a dangerously large current from the battery itself, are rarely needed or used; the internal resistance of the battery, especially where the cells are connected in series, as is generally the case, is sufficient to render the generation of a dangerously large current impossible.

The maximum current from a single set of gravity cells connected in series, even if short-circuited, will not exceed $\frac{e}{b}$, which is, approximately, $\frac{1}{3}$ ampere if the internal resistance b and the electromotive force e per cell are 3 ohms and 1 volt, respectively. This current will do no damage to the wiring or the cell, although if it continues to flow long enough, it might injure the insulating covering on the wire of the coils. But with dynamos, converters, and storage cells, an injuriously large current will flow if the external resistance approaches near enough to zero, so that, in the use of dynamos, converters, and storage cells, precautions must be taken that are unnecessary with gravity cells. In order to prevent injury to the machines or to storage batteries, provision should be made to limit the maximum current to a safe value, or to open the circuit if it exceeds this safe maximum value, for too large a current might burn out the dynamo armature or throw off the belt, and in the case of storage cells the plates might buckle or disintegrate.

21. Fuses and Circuit-Breakers.—In the main circuits leading from the machines or storage batteries are placed fuses or magnetic circuit-breakers that will open these main circuits

should the current exceed a given maximum value. In the supply side of converters and storage batteries, a circuit-breaker is used that opens the circuit not only if the current exceeds a certain maximum value, but also if it falls to zero. Automatic circuit-breakers are shown and described elsewhere. Fuses used to protect instruments, circuits, dynamos, or other devices should have a somewhat higher rating than the greatest current desired in the circuit. For instance, eight 4-ohm sounders will require 2 amperes, but a 3-ampere fuse should be used for their protection.

22. Non-Inductive Resistance.—To keep the current from exceeding a safe value in any one line supplied from a dynamo or storage battery, it is customary to insert a non-inductive resistance in every telegraph line between the dynamo or storage battery and the telegraph instruments, so that the current in any line cannot exceed the quotient obtained by dividing the potential used on that line by this non-inductive resistance, even if a short circuit does occur in the line or apparatus beyond this so-called dead resistance. This dead resistance is placed behind or above the switchboard, and as near the generator mains as is convenient. Generally, it contains from 2 to $2\frac{1}{2}$ ohms per volt, which would limit the current to from $\frac{2}{5}$ to $\frac{1}{2}$ ampere. Furthermore, with these coils in circuit, the injurious arcs that would otherwise occur at the telegraph keys, pole changers, and transmitters, in case of a short circuit, are avoided, or are, at least, much diminished in volume.

Non-inductive resistances are also used for various other purposes; for instance, to equalize the resistance in a number of wires fed by one dynamo, to equalize the resistance of loop circuits, and to produce a fall of potential by the introduction in a circuit of a resistance, etc. These are explained as they come up in connection with various systems.

23. The Western Union Telegraph Company formerly used German silver wire, wound non-inductively, for its resistance coils, but it replaced the coils by incandescent lamps having the proper resistance. The company claims that the German

silver wire caused considerable trouble by breaking so often and that the lamps gave better satisfaction. Incandescent lamps form an almost perfect non-inductive resistance. The Postal Telegraph Company does not seem to have had this trouble, for it still uses German silver or other high-resistivity wire. The wire is wound non-inductively on hollow spools set upright so that the air can circulate around them, in order to keep them from becoming too hot. Formerly tin spools were used but now special wire wound on porcelain, or clay, spools and the whole dipped into enamel and baked hard is used.

A coil is wound non-inductively by doubling the wire at the middle of the length to be wound on the coil, and then winding the two strands of the wire on the spool together, keeping them as close together as possible. Thus, the current in passing through the coil always circulates through two adjacent wires in opposite directions, the inductive effect of one neutralizing that of the other. All resistance coils and rheostats used in telegraphy are wound non-inductively in this manner, unless something to the contrary is stated. Where an inductance is desirable, as in the case of coils used in simultaneous telegraphy and telephony, they are usually called **impedance,** or **retardation,** or **choke,** coils.

GROUPING THE CIRCUITS

24. If it can be avoided, more than one line should never be connected through the same disk and lamp to the source of current where dynamos are used. Especially should this be avoided when connecting up a long, or high-resistance, circuit and a short, or low-resistance, circuit, and also when both circuits are low in resistance. It is permissible to supply two high-resistance circuits through the same disk and lamp. If a high- and a low-resistance circuit are joined through the same disk and lamp to the dynamo, every time the key on the low-resistance circuit is opened or closed, there is very apt to be sufficient variation in the current in the high-resistance circuit to cause trouble. Where both circuits are low in resistance, the operation of either key may affect the strength of current flowing in the other circuit.

If, instead of one lamp common to both lines, a separate lamp is put between each line and the dynamo, there will be no such fluctuation in the current due to the operation of the key in either circuit.

25. For example, suppose that two circuits, the resistances of which are 4,000 and 1,500 ohms, respectively, are connected through the same lamp to the 140-volt dynamo. These values are extreme and in practice should never be so connected. The resistance of the lamp in this circuit will be about 300 ohms. When only the 4,000-ohm circuit is closed, the current will be $\frac{140}{4{,}000+300}=.0325$ ampere. But when both lines are closed, the combined resistance of both circuits will be $\frac{4{,}000\times 1{,}500}{4{,}000+1{,}500}+300=1{,}391$ ohms and the total current will be $140\div 1{,}391=.1006$ ampere, which will divide through the 4,000-ohm and 1,500-ohm lines inversely as their resistances.

If x = current in the 4,000-ohm line, and y = current in the 1,500-ohm line, $\frac{y}{x}=\frac{4{,}000}{1{,}500}$. Adding 1 to both sides of this equation, gives $\frac{x+y}{x}=\frac{4{,}000+1{,}500}{1{,}500}$. But $x+y$ is the total current; that is, .1006 ampere; hence, $\frac{.1006}{x}=\frac{5{,}500}{1{,}500}$. Solving this, $x=.0274$ ampere. Therefore, .0274 ampere will flow in the 4,000-ohm line. Hence, the current in the 4,000-ohm line decreased from .0325 to .0274; that is, the current in the high-resistance line decreased over 15 per cent. when the key on the other line was closed.

26. If both lines have a resistance of 2,000 ohms, the current through one when the other is open will be $140\div 2{,}300=.0609$. When both are closed, the current in each will be $\frac{1}{2}\left(\frac{140}{1{,}000+300}\right)=.0538$. In this case, the current in the first circuit decreased about 10 per cent. when the second key was closed. Even with two lines, each of 3,000 ohms, the current will vary about

8 per cent. These variations are due to the one lamp that is in series with both lines.

27. When a large number of lines or local circuits are supplied with current from one dynamo or storage battery, care must be taken to use large enough lead or main wires between the dynamo and the point where the various circuits join together. For if the product of the total current and resistance of the mains gives too large a drop in voltage the operation of the various instruments will interfere with one another. Care must also be taken that the heating effect is not so large as to heat injuriously the insulation on the wire or to cause a fire. No rules can be given for such cases as it depends on the kind and thickness of insulation, sectional area of the wire, with what material it is surrounded or enclosed, and the temperature of the surrounding air.

POSTAL TELEGRAPH COMPANY'S ARRANGEMENT

28. When installed in 1894, the main-line switchboard of the Postal Telegraph Company in New York City consisted of six sections of 50-wire, double-spring jack-boards and two spare sections not then required. There were also two sections of four rows of spring jacks constituting a loop, or *leg board*, as it is called. At one side of this board was an equalizing board, by means of which the resistance of all loop circuits could be readily equalized, which is one of the requirements of a dynamo system. All legs, or loop circuits, are generally brought up to a resistance of 150 ohms.

On the main-line switchboard, the bottom row of disks is grounded. The next ten rows above supply the currents varying from 40 to 200 volts, two rows of disks being assigned to each pressure.

In all the large offices of the Postal Telegraph Company, the generator plants are of about the following voltages: 40, 85, 130, 200, and 385 volts. In their New York office, there were four machines supplying positive currents at 85, 130, 200, and 375 volts, and four supplying negative currents at the same

voltages. There was one 40-volt machine, also, for supplying sounders and other local instruments and branch-office circuits. Five machines were held in reserve to relieve, if necessary, any of the foregoing. In the larger cities, there are usually spare sets, but in most places a few spare armatures should be sufficient, for the armature is the only part of the machine that is apt to fail. Nowadays, machines are so well built and protected by cut-out devices that an injury to a machine is a rare occurrence.

29. Only two machines are shown in Fig. 8, but the others are connected up in exactly the same manner. One pole of each machine is grounded; the other pole is connected through

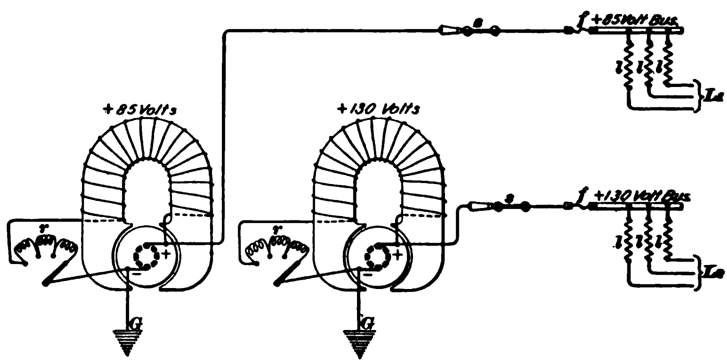


FIG. 8

a switch *s* and fuse *f* to its own particular bus-bar. All line wires are connected through non-inductive resistance coils *l* to the bus-bars. Each line in the group L_1 is supplied with positive current from the 85-volt machine, and each wire in the group L_2 with positive current from the 130-volt machine. It should be noticed that the machines shown are entirely independent of each other; an accident to one machine does not affect the other. The machines were converters, but, for the sake of simplicity, the two machines are represented as self-excited dynamos. These converters were all run by current from one constant-potential 125-volt dynamo, which was also utilized for lighting the building. In addition to these sets,

there were six or more machines employed as intermediate batteries and for testing purposes.

In the dynamo room, there were specially designed knife switches for the rapid exchange of one machine for another on the leads going to the bus-bars above or behind the main-line switchboards in the operating department. The conditions in each city may differ, and no two offices, either Postal Telegraph or Western Union, are necessarily equipped in exactly the same manner.

UTILIZING ELECTRIC-RAILWAY CURRENT FOR TELEGRAPH CIRCUITS

30. The following method of supplying local and main-line telegraph circuits with current from the 500-volt circuit of electric railways shown in Fig. 9, was described in the Telegraph Age, by Mr. Wm. H. Deane, who employed it on the telegraph circuits of the Brooklyn Rapid Transit Company in 1900.

"A wooden box 18 inches square and 8 inches deep is lined with thin sheet asbestos and fitted with sixteen 110-volt, carbon-filament lamps of 16 candlepower each and wired in series. The current is led from the feeder by a wire that passes through the regulation porcelain tubes used in electric-light work to a small knife switch located in the box and then through the bank of lamps, and out through another tube and grounded, preferably to the rail.

"One end of the telegraph line or local circuit that is to receive this current is grounded and the other end is brought into the box of lamps and passed through a ½-ampere fuse before reaching the lamp connection. In supplying a main line, it is of course understood that this apparatus can only be applied at one end of a grounded telegraph wire. To ascertain quickly the point that will furnish the needed current, the end of this conductor should be touched to the lamp connections and, starting from the grounded end of the bank, moved lamp by lamp upwards until the instrument in the circuit shows that it is supplied with the proper amount of current to do the

work required. When this is decided upon, the wire can be permanently fastened to the particular connector selected. The following telegraph lines and quite a number of locals were equipped in this way and gave satisfaction: Brooklyn Elevated Division No. 1 telegraph line, consisting of 25 miles of No. 12 insulated iron wire and looped into 24 relays of 50 ohms resist-

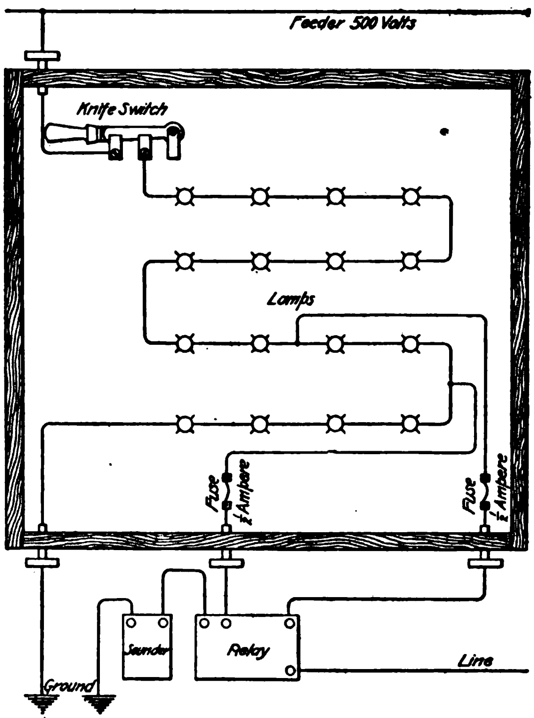


Fig. 9

ance each; this circuit worked strongly and was tapped between the sixth and seventh lamps from the ground end. Kings County Elevated Railroad Division, consisting of two line wires, each 8 miles long, of the same wire just mentioned, and equipped with 17 relays of 30 ohms resistance, was tapped between the fifth and sixth lamps. Local 4-ohm sounders worked strongly when tapped between the fourth and fifth

lamps, and when sounders of 20 or 30 ohms were used, excellent results were obtained by tapping between the first and second or second and third lamps."

31. Necessary Precautions.—"Care should be taken not to unscrew any of the lamps between the tap point and the ground without first opening the knife switch, as the telegraph circuit is instantly flooded with a rather heavy current, and although the fuse would protect the circuit, still an unpleasant shock might be given to some one working the wire at the time. The same trouble would be experienced should a filament break in one of the lamps on this end of the bank of lamps; but this rarely happens, as these lamps are not subjected to the hard usage of those used for lighting purposes. Only one case of this kind occurred in a year on the above circuits. This was caused by an old lamp being accidentally used in setting up the apparatus. Great care should be taken that the entire work is done on the strict lines laid down by the underwriters and boards of electrical control."

32. There was not much trouble from variations of current, and then only at points where there were no feeders and where a tap was made to the trolley wire direct. Over 200 gravity cells were displaced, and these boxes, enabling the electric railway current to be used, were installed wherever locals were used, with the most gratifying results.

STORAGE BATTERIES IN TELEGRAPH OFFICES

STORAGE BATTERIES FOR LOCAL CIRCUITS

33. Sounders Operated From Storage Battery.—A method for supplying sounders with current from a storage cell that is charged from a direct-current electric-light circuit is shown in Fig. 10. Four-ohm sounders S are connected in multiple across a 2-volt storage cell B; they are controlled by the relays R. A fuse f is placed in each sounder circuit. In the charging circuit are the main fuses f', a double-pole knife

switch K, and the lamp bank. By means of the switch K, the charging current may be kept flowing through the battery as long as is necessary to keep the cell sufficiently charged. The cell can be charging while the sounders are in use or at any other time.

Sometimes, in small towns, the current is shut off from the electric-light circuit early in the morning, and perhaps at other times. Whenever this happens the storage battery must be disconnected from the mains by opening the switch K. In such localities, the switch K must not be left closed during the night in order to charge the battery, unless there is in the charging circuit an automatic device that will open the circuit in case the charging current drops to zero. This is necessary

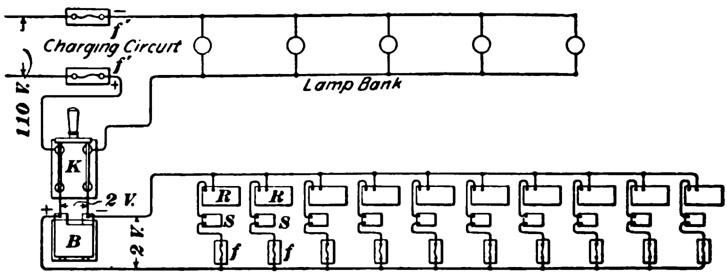


FIG. 10

in order to prevent the battery from completely discharging itself through the charging circuit, as it might do if there were no such automatic device to open the circuit. In almost any case, it would be better to have an overload-and-underload circuit-breaker instead of the fuses f' and double-pole switch K.

34. If in the arrangement shown in Fig. 10, there are ten 4-ohm sounders and sufficient resistance in series with each sounder so that each receives a maximum current of .25 ampere, then the total current is $10 \times .25 = 2.5$ amperes. A cell having a maximum safe discharge rate of $2\frac{1}{2}$ amperes will be needed. The cell may also be charged at this rate. To do this, five 16-candlepower, 110-volt, carbon-filament lamps, in multiple with one another, should be connected in the charging circuit in series with the storage cell, as shown. Each lamp will allow

about $\frac{1}{2}$ ampere to flow through it, the five giving, therefore, the desired $2\frac{1}{2}$ amperes.

35. Storage Cell at Branch Office Charged From Main Office.—Where a number of lines run from a main office to one branch office near by, it is sometimes practical to charge a storage cell used at the branch office for operating the sounders by the current coming through the line wires from the main office. This can be done provided there is enough current in all of them to furnish about 20 per cent. more ampere-hours than is required by the branch-office sounders. An arrangement, due to Mr. Athearn, for charging a storage cell in this manner is shown in Fig. 11; here *P R* are polarized relays, and *P C* are pole changers used in duplex and quadruplex systems. In series with the contact points of each polarized relay there are two sounders, one at the main office and one at the branch office. The sounder at the main office enables the attendant there to tell whether that circuit is working all right. The receiving operator at the branch office receives the messages on this receiving side, or **leg**, of the loop, as it is called, by means of the sounder *S*. A sending operator at the branch office controls the pole changer *P C* at the main office by means of the key *K*. This circuit is called the **sending leg** of the loop circuit. The sounder in this circuit at the branch office enables the branch-office operator to tell whether this circuit is working all right. These receiving and sending legs are the same as the circuits marked *receiving side* and *sending side* in the various figures given in other Sections showing the local circuits of duplex and quadruplex sets.

36. In Fig. 11, all switches have been omitted, for the sake of clearness. Besides such circuits, there may be lines between the main and branch offices containing simply keys *k* and sounders *M* for business merely between the main and branch offices. If the instruments in each one of these branch-office lines required $\frac{1}{4}$ ampere, the total current flowing from the main office into the branch office would be $5 \times \frac{1}{4} = 1\frac{1}{4}$ amperes. If a storage cell is inserted in this circuit as shown, this current has to flow through it or the local sounders *s* before it can reach

the ground through which it returns to the main office. The part of the current that flows through the storage cell will tend to keep the cell charged. Thus, the storage cell is being charged more or less all the time that current is coming from the main

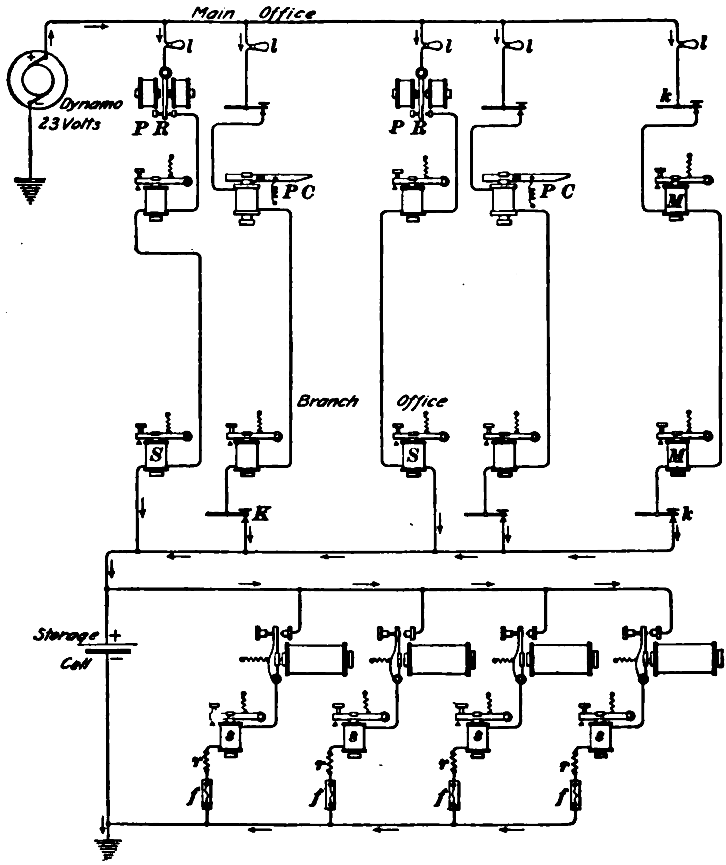


Fig. 11

office in excess of that being used by the local sounders *s*. When the sounders are using more current than is coming from the main office, the cell must supply this excess current.

37. In order that the current from the main office can charge the cell, it must be connected so that its electromotive

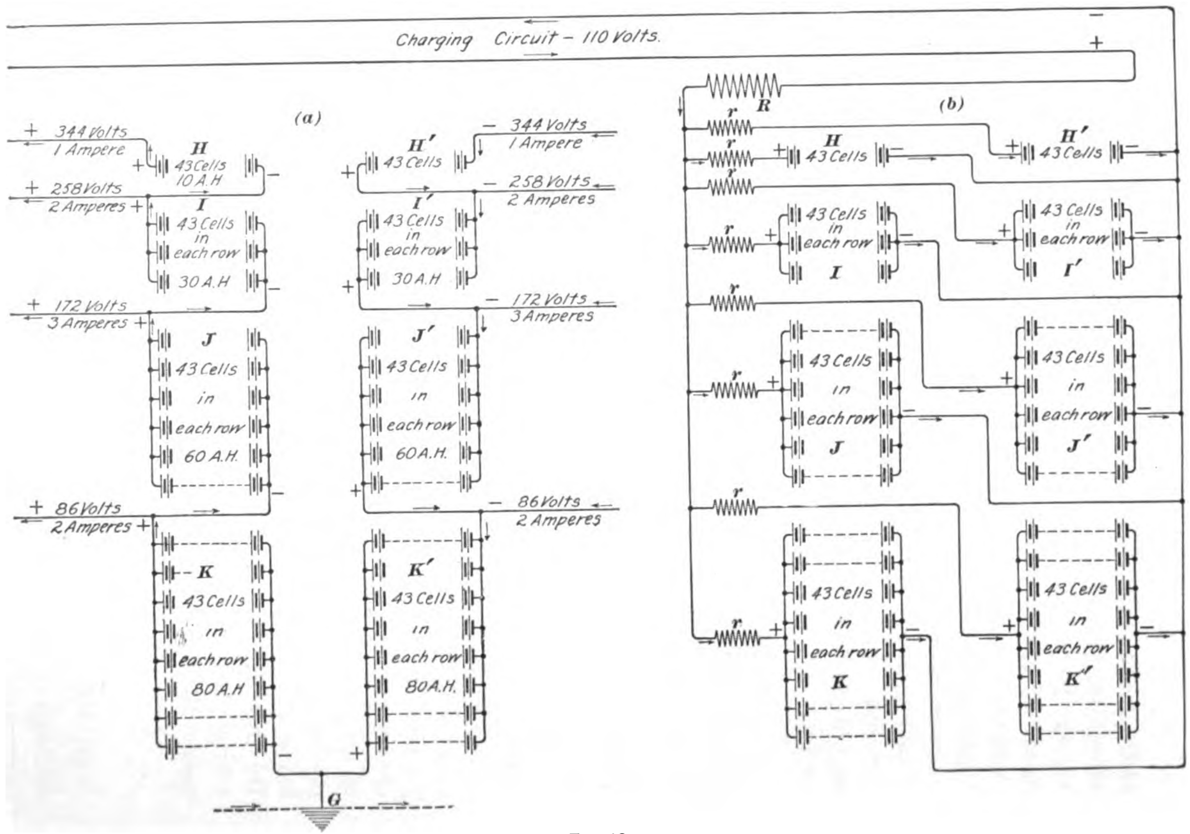
force, 2 volts, will oppose the 23 volts generated by the main-office dynamo. This is equivalent to reducing the main-office voltage from 23 to 21 volts. To counteract this, the main-office voltage may be raised to 25 volts, giving an effective electromotive force of 23 volts in the circuits shown in Fig. 11. However, the same object is accomplished in a more convenient manner by reducing the resistance of each lamp in these particular loop circuits just enough so that the ordinary 23-volt dynamo, which supplies other circuits besides these, will still be able to send $\frac{1}{2}$ ampere through each of these branch-office circuits.

38. All the local sounders *s* in the branch office are connected, as shown in Fig. 11, across two leads running to the terminals of the storage cell. As the electromotive force of a single storage cell is about 2 volts, it is necessary, if 4-ohm sounders are used, to insert a non-inductive resistance *r* of about 4 ohms in series with each sounder, in order to limit the current in each local sounder to $\frac{1}{4}$ ampere. It is best to put a fuse *f* in each circuit, but one in each lead to the storage cell may be sufficient.

Ordinarily, the number of circuits through which the charging current flows and the number of local branch-office sounders supplied from the cell should be so proportioned that the charging in ampere-hours shall exceed the discharging capacity in ampere-hours by about 20 per cent., provided the rate of discharge is not excessive. In some cases, it may be feasible to leave the charging current on all night and during Sunday. By thus charging at times during which discharging is not taking place, the number of discharging sounder circuits may exceed the number of charging circuits from the main office.

STORAGE BATTERIES FOR MAIN LINES

39. An arrangement of storage batteries suitable for use on telegraph lines of various lengths is shown in Fig. 12. Each battery shown represents 43 cells and therefore about 86 volts, and its size or number of plates in parallel has been made proportional to the required capacity in ampere-hours of the group



Charging Circuit – 110 Volts.
(a)
344 Volts
1 Ampere
H
43 Cells
10 A.H
258 Volts
2 Amperes
I
43 Cells in each row
30 A.H
172 Volts
3 Amperes
J
43 Cells in each row
60 A.H.
86 Volts
2 Amperes
K
43 Cells in each row
80 A.H
H′
43 Cells
I′
J′
K′
G
(b)
R
r
H
43 Cells
H′
43 Cells
I
I′
J
J′
K
K″

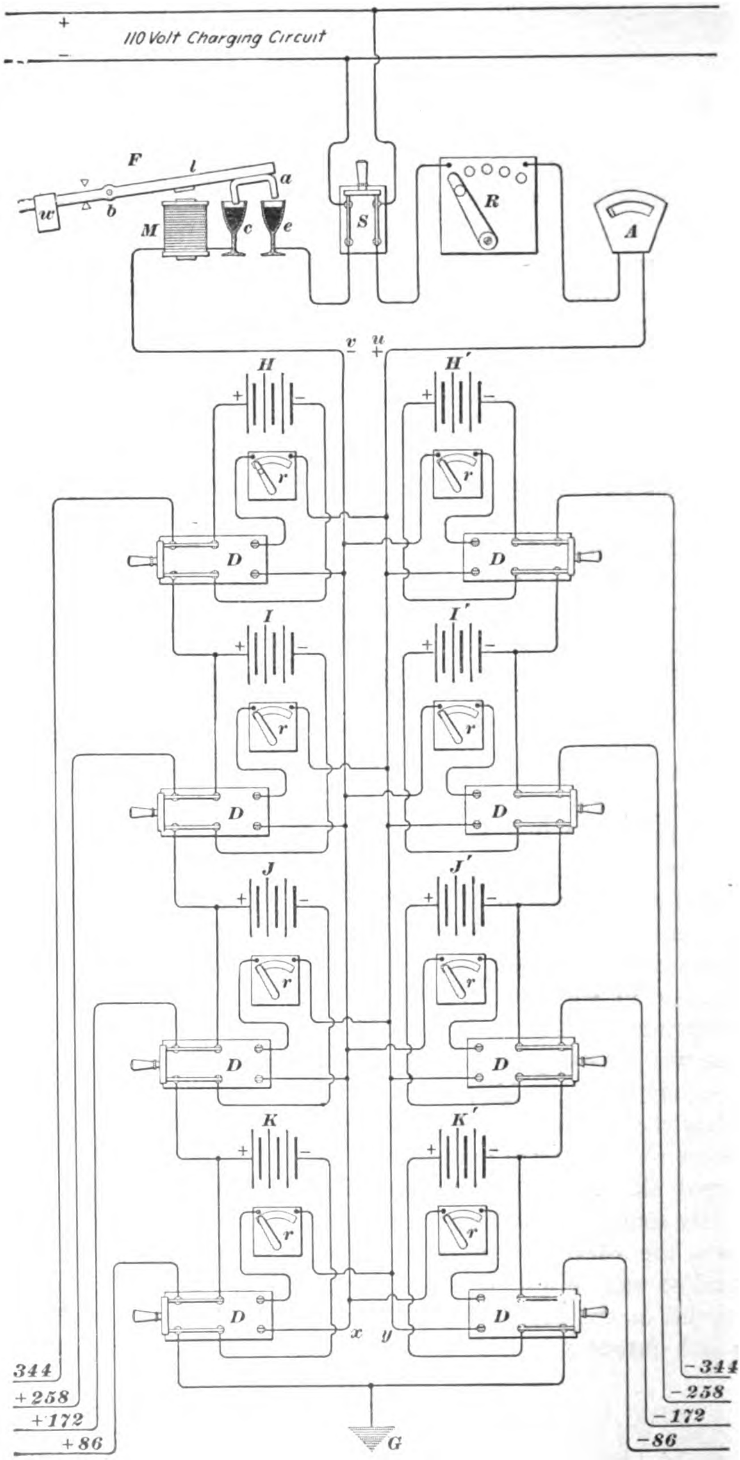
Fig. 12

that it represents. In (*a*) the cells are arranged in two groups, one furnishing positive and the other negative current for use on the line wires. All sets furnishing positive currents are joined in series, as are also the negative sets; it is thus possible to get current, either positive or negative, at 86, 172, 258, and 344 volts.

Suppose the current used at 344 volts is 1 ampere, at 258 volts 2 amperes, at 172 volts 3 amperes, and at 86 volts 2 amperes, and, further, that all the batteries are of such an ampere-hour capacity that they all become discharged after the same interval of time, say 10 hours. Then the capacity of the batteries H and H' would evidently be 10 ampere-hours; of the batteries I and I', $(1+2)\times 10=30$ ampere-hours; of batteries J and J', $(1+2+3)\times 10=60$ ampere-hours; and of batteries K and K', $(1+2+3+2)\times 10=80$ ampere-hours. Consequently, the batteries K, K', J, J', and I, I' will require, as represented in Fig. 12, eight, six, and three times the plate area, respectively, of the battery H or H'.

40. In order to charge these batteries from a 110-volt circuit, they should be connected as shown in Fig. 12 (*b*), where each battery of 43 cells is connected directly across the 110-volt mains of the charging circuit. If they were all discharged equally, they would all become charged in the same length of time. An adjustable resistance R should be placed in the main charging circuit, and preferably also an adjustable resistance r in each battery circuit. By these resistances, the charging current can be suitably controlled, thus preventing the whole battery or any individual set from being charged at too high a rate, which is apt to be the case for a short time after the batteries are first connected to the charging circuit. Some resistance will be needed at R all the time if the voltage across the charging circuit is much above 110 volts.

By connecting a voltmeter across the terminals of the various sets, the attendant can tell when each becomes fully charged, and so will be able to disconnect each set from the charging circuit at the proper time. There is not, however, nearly so much danger of injuring a cell by overcharging it as from over



110 Volt Charging Circuit
+
−
F
l
a
w
b
M
c
e
S
R
A
v
u
−
+
H
H′
I
I′
J
J′
K
K′
D
r
x
y
G
344
+258
+172
+86
−344
−258
−172
−86

FIG. 13

discharging it. The arrows show the direction in which the currents flow in (*a*) while discharging and in (*b*) while charging.

41. Switch Connections.—In Fig. 13 is shown a simple way in which the cells may be arranged whereby they can be disconnected from the discharging and connected to the charging circuit by the proper manipulation of knife switches. A double-pole switch *S* is so placed that the main charging circuit can be entirely cut off from all the cells. With the double-throw switches *D* connecting the center and outside contacts, the batteries are connected in two series sets to the discharging circuits. The underload or no-load device *F* consists of a magnet *M* connected between a metallic cup *c* containing mercury and the wire *v*; a lever *l* pivoted at *b* and having at the forward end an inverted **U**-shaped copper wire *a*, the two downwardly projecting ends of which can dip, when the forward end of the lever *l* is depressed, into the mercury in the two metallic cups *c* and *e*; and an adjustable weight *w* at the rear end of the lever *l*. The mercury cup *e* is joined to one terminal of the double-pole switch *S*. When the forward end of the lever is pushed down, the two mercury cups are connected together by the mercury and the copper wire *a*, thus closing the circuit between the two cups *c* and *e*. The weight *w* can be adjusted along the lever *l* so as to open the circuit when the current and the resulting pull of the magnet decreases to zero or to any desirable small value.

42. Each battery, although only 3 cells are shown, consists, in this case, of 43 cells in series. One group *H* and *H'* has a capacity of 10 ampere-hours; another *I* and *I'*, a capacity of 30 ampere-hours; the third *J* and *J'*, a capacity of 60 ampere-hours; and the fourth *K* and *K'*, a capacity of 80 ampere-hours, as in Fig. 12. Adjustable resistances or rheostats *R* and *r* serve the same purpose as the corresponding resistances in Fig. 12.

To charge the batteries, close the *D* switches so that they will connect with the lead wires *u y* and *v x*. In this position, all the batteries are in parallel, in the proper position for charging. Then, with all the resistances in the rheostats *R*

and *r*, close the switch *S* and also the underload circuit-breaker *F* by pushing down the forward end of the lever *l*, thus connecting the cup *e* with the cup *c*. The circuit is now closed, and the current flowing through the magnet coil *M* will hold the lever *l* down. Adjust the resistances *R* and *r* until the correct charging current, as indicated by the ammeter *A*, is obtained. If, for any reason, the current falls to zero, or decreases to such a value that the downward pull of the weight *w* is greater than the downward pull of the magnet *M*, the lever will fly up, pulling the connection *a* with it, and so open the circuit between the two mercury cups *c* and *e*. In place of this underload device *F*, a regular underload circuit-breaker would be preferable. Any one of the *D* switches may be opened from time to time, as the battery to which it belongs becomes fully charged. This state is conveniently determined by the indication of a voltmeter connected directly across the set.

AUTOMATIC STARTING BOX

43. When the simple form of starting box is used for starting a direct-current motor, it is necessary to see that the handle is moved back to the off-position every time the machine is shut down, so that all the resistance will be in the circuit the next time the machine is started up. If this is not done and the switch is thrown in, by starting up with the resistance all out of the circuit, there will be such a heavy rush of current as to injure the machine or blow the fuse. In order to obviate this, motors and motor-dynamos are now usually provided with automatic starting boxes, the switch lever of which automatically flies back to the off-position when the current is shut off. They are also generally provided with an arrangement for throwing the switch lever back, and thus breaking the circuit, when the motor is overloaded. The same arrangement may be used for a rotary converter where the resistance in the box is not used to regulate the voltage on the dynamo side.

Fig. 14 shows an arrangement of an automatic starting box, made by the General Electric Company, that will serve to illustrate the action of automatic starting rheostats and the use of a

motor-dynamo for supplying current to local-sounder circuits. The resistance in the starting box is connected between the contact points, as shown, and the arm is in the running position with the resistance all cut out. The contact arm is moved over against the action of a spiral spring in the hub and is held in position by a catch *a*, which fits into a notch in the hub of the lever *b*. This lever carries an armature *c*, which is held down against the action of a spring by the magnet *m*. The exciting coil of this magnet, in the case of a shunt machine, is connected in series with the field; in the case of a series machine, it is wound with heavy wire and connected in series with the motor. If the current is cut off in any way, the magnet releases the armature and the switch lever flies back to the off-position.

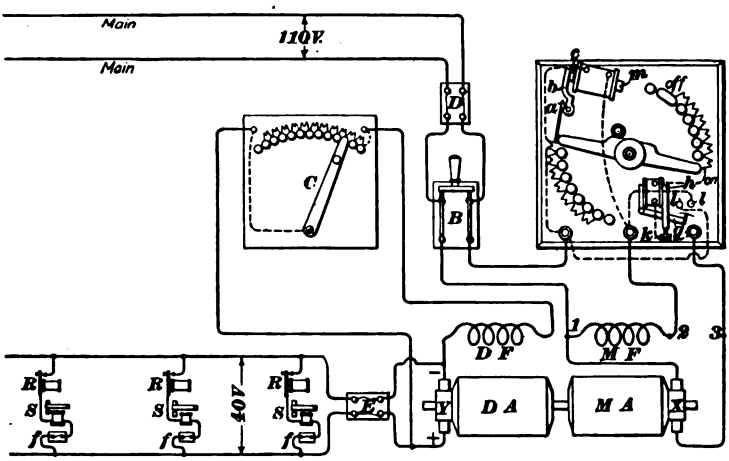


FIG. 14

44. Overload Device.—The automatic starting box shown in Fig. 14 has also a device that will cut off the current from the main circuit should the machine be overloaded. In some cases this is necessary in order to save the machine from excessive heating or burning out. An overload is due to an excessively large current being taken from the generator side of the machine; that is, from the brushes against the *Y* commutator. This *overload* device, as it is called, consists of an electromagnet, the coil of which is connected in series with the armature *M A*.

This magnet is provided with a movable armature *g*, the distance of which from the pole *h* may be adjusted by the screw *k*. When the current exceeds the allowable amount, the armature is lifted, thus making connection between the pins *l*. This connection short-circuits the coil of the magnet *m* and the lever goes to the off-position.

45. Connections of Dynamo Side.—In Fig. 14, the connections of the dynamo side of the motor-dynamo have also been shown. In the dynamo-field circuit is the rheostat *C*, by means of which the voltage at the dynamo terminals may be regulated; *E* is a fuse block in the main telegraph circuit, and *f* are fuses in each individual local circuit. A preferable arrangement, if the field coil is properly designed for the high voltage, is to connect it between *1* and *2* instead of between the brushes of the dynamo armature, the rheostat *C* being retained in series with the dynamo field, as shown here. By so doing the dynamo field will be excited directly by the current from the 110-volt mains, and thus the loss due to the transformation of the dynamo-field current will be avoided.

LOAD UPON DYNAMOS AND STORAGE BATTERIES

46. Size of Dynamo Required.—When a number of circuits, each requiring the same amount of current, are supplied by one dynamo or storage battery, the machine or battery must be large enough to supply a total current equal to the current in one circuit multiplied by the number of similar circuits. Thus, if there are 60 local circuits, containing sounders, pole changers, or transmitters, and each requires .25 ampere, the total current that the dynamo or storage battery must be capable of supplying is 15 amperes. If the voltage desired is 23, a 345-watt dynamo will be large enough. For such a small machine, some form of motor-generator, dynamotor, rotary converter, or rectifier would probably be used. However, it is best to get a machine at least a little larger than is actually required and, preferably, one large enough to provide for a reasonable increase in the number of local circuits.

In estimating the size of a required dynamo or the maximum current discharge capacity of a storage battery, it is customary to allow 250 milliamperes for each 4-ohm sounder or equivalent local circuit, 50 milliamperes for each 150-ohm-relay line circuit, 50 milliamperes for each duplex circuit, and 100 milliamperes for each quadruplex circuit.

47. Size of Storage Battery Required.—The information that will enable one to choose the proper motor is not sufficient to determine the size of a storage battery required to do the same work, except perhaps where the battery is being continuously charged while in use. Whenever the battery is charged and discharged at different times, it is necessary to determine not only the maximum output, in amperes, but also the total ampere-hours required from it between the end of a charge and the beginning of the next charge. For instance, one battery may be charged regularly once in each 24 hours when not in use, as at night, or two batteries may be required so that one can be charged during that portion of the day that the other is in use. Furthermore, it may happen that no current can be obtained for charging purposes on Sunday or on a holiday; in which case if the holiday comes on Saturday or Monday, the battery must have enough ampere-hour capacity to carry its load for 3 days.

48. When a sounder is working it requires only about one-half as much energy as when idle and on closed circuit, because it is open about one-half the time when working. Hence, a 4-ohm sounder working for 8 hours requires $\frac{1}{2} \times .25 \times 8 = 1$ ampere-hour, whereas it would require 2 ampere-hours if idle and its circuit left closed. Whenever an office is without an attendant, all local circuits should be left open when supplied with current from any source, except perhaps closed-circuit primary cells, in order to save current and useless wear of the instruments themselves.

To determine the size of a storage battery it is therefore necessary to calculate the total number of ampere-hours required for the whole period between successive charges; this time may be 12 hours, one or more days, or a week, as the case may be.

The number of ampere-hours required will determine the size of each cell; the voltage required will determine the number of cells to be connected in series in each battery. Suppose that there are 50 line circuits, each requiring .05 ampere at 100 volts for an average of 8 hours a day, and that two batteries are necessary because one must be always in useful condition. If the line circuits are closed 60 per cent. of the time only, the battery will have to furnish $50 \times .05 \times 8 \times .6 = 12$ ampere-hours. Hence, 100 volts $\div$ 2 volts $=$ 50 cells, each having a capacity of 12 ampere-hours, will be required for each battery and twice that many cells for both batteries. If the battery cannot be charged on Sunday or a holiday, the size of each cell must be three times as large, or at least have plates of such size and number as to provide three times the active surface.

The number of ampere-hours required to charge the battery will be greater than the output because its efficiency is, of course, less than 100 per cent. For example, if 12 ampere-hours are required and the efficiency is 70 per cent., $12 \div .7 = 17.1$ ampere-hours will be required to charge the battery.

49. It is customary to allow for a period of 24 hours 1 ampere-hour storage-battery capacity for each main line requiring about .045 ampere and to count a polar duplex as two lines and a quadruplex as five lines. Duplex and quadruplex circuits are never open when in use; they are using either negative or positive current all the time and the quadruplex consumes more current for one position of the transmitter than for the other position. The battery must also be enough larger to provide for all extra circuits required in emergencies. As much as 45 per cent. may be allowed for growth and emergencies in large offices.

Where the source of current supply can be absolutely relied upon every hour in the year, two storage batteries may be used, each large enough to supply all the line circuits for 12 hours while the other is being charged. Otherwise each battery must probably be large enough for 3 days' uninterrupted service. The most economical method, where it is practicable, is to charge the battery while it is in use, no duplicate battery being required.

ECONOMICAL AND PRACTICAL ARRANGEMENTS

50. The most economical arrangement of local circuits is to use sounders, transmitters, and other local instruments of such resistance that they can be connected directly across the source of current; but on account of their relatively high inductance the local instruments operate with more snap the larger the non-inductive resistance connected in series with each instrument. Hence, it is customary to connect at least as much non-inductive resistance in each local circuit as there is resistance in the local instrument, and in many cases much more non-inductive resistance is used. This of course necessitates the use of a higher electromotive force than would be required to operate the local instruments without the non-inductive resistances, hence the cost of the energy used is greater and the sparking at contact points may be more injurious. However, the higher electromotive force tends to eliminate troubles due to corroded or dirty contacts and a slight variation in resistance of lead wires or instruments will have a smaller proportionate effect upon the strength of the currents.

In broker offices, the American Telephone and Telegraph Company frequently connects 20-ohm sounders in series with the relay contacts and a non-inductive resistance of 680 ohms across a 110-volt, direct-current, lighting circuit. Where the direct-current lighting circuit is not available, this company operates the 20-ohm sounder by nine dry cells connected in three groups in series, each group containing three cells in parallel. With this arrangement, one bad dry cell will not appreciably affect the operation of the sounder.

LOCAL AND MULTIPLEX WIRING FROM 110-VOLT MAINS

51. An office that is supplied with current from a three-wire, 110-volt circuit, usually from a city or town electric-light station, is wired by the Postal Telegraph-Cable Company about as shown in Fig. 15. Between the two outside wires *k* and *l*, there exists a potential of 220 volts, one outside *l* being 110 volts

above the neutral *n* and the other outside wire *k* 110 volts below the neutral *n*. This so-called neutral wire *n* is usually

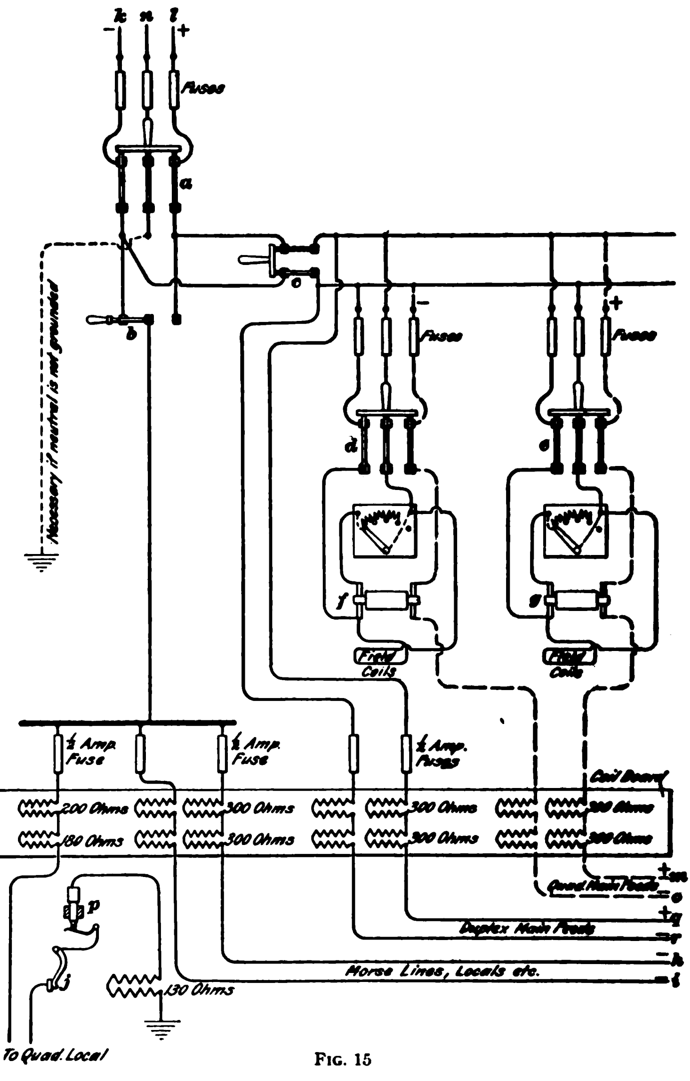


FIG. 15

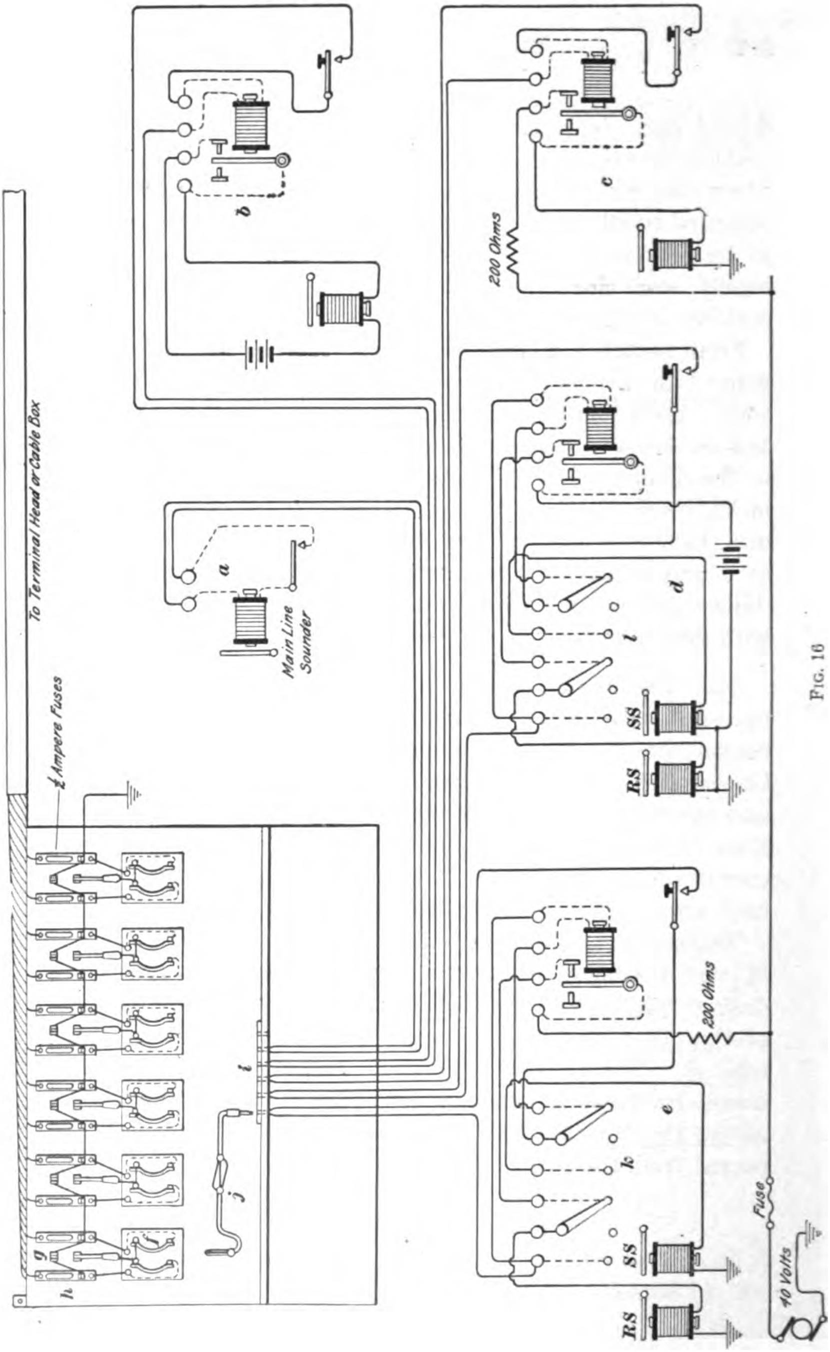
grounded by lighting companies, but if it is not so grounded it must be grounded in the telegraph office as indicated by the

dotted line. The main switch *a* is provided so that all connection between the office and lighting mains may be broken when desired. The switch *b* allows circuits, which may be operated equally well with either positive or negative potential, to be connected to either outside main wire *k* or *l*. By this means, each circuit may be supplied with 110 volts, either positive or negative.

From switch *b*, a wire extends to the coil boards where as many branches as necessary pass through fuses and resistance coils. Each line that supplies the local circuits of quadruplex and duplex sets, passes through 200- and 180-ohm coils, then to the quadruplex and duplex tables, and back through spring jacks *j* – pin jack *p* – 130-ohm coils to ground. The Morse line, local and call circuits are supplied through such wires as *i* and *h*, while the positive and negative sides of polar duplex sets are supplied through pairs of wires like *q* and *r* with 220 volts.

52. In order to supply the quadruplex main circuits it is necessary to have a potential higher than 220 volts. For this reason two dynamotors, called *boosters* in such cases, are used. One supplies the required positive potential through the lead *m* and the other the same negative potential through the lead *o*. Each booster has its field connected directly across the 220-volt circuit when the switches *d* and *e* are closed. In series with each armature is a starting box.

The negative side of the circuit passes through the armature of one booster *f*, where its potential is raised as high as desired, while the positive side passes through the armature of the other booster *g* where its potential is raised a similar amount. Three-blade switches *d* and *e* are used and each circuit has fuses of suitable capacity. A double-pole switch *c* allows the boosters and the duplex-main feeds to be disconnected from the outside wires.



To Terminal Head or Cable Box
¼ Ampere Fuses
Main Line Sounder
200 Ohms
200 Ohms
Fuse
10 Volts
RS
SS
RS
SS
a
b
c
d
e
f
g
h
i
j
k
l

FIG. 16

BRANCH-OFFICE WIRING

53. In Fig. 16 is shown the wiring used by the Postal Telegraph-Cable Company for branch offices. The cable from the terminal head or cable box is brought to fuses and carbon arresters *h* mounted on porcelain bases and secured to the face of the switchboard. These are connected to one side of spring jacks *f*, which also are mounted on porcelain bases and secured to the face of the switchboard. Between each pair of arresters is a small knife switch *g*; by closing one knife switch the movable portions of the two spring jacks immediately below it are connected to ground. As the two binding posts connected to the two movable parts on each pair of spring jacks are joined together, they form a closed circuit between the two corresponding wires constituting a loop, when there are no wedges inserted in the jacks. Closing the ground switch above such a pair of jacks grounds both legs of the loop. Any desired number of jacks *i* designed to receive two-conductor round plugs may be mounted in the shelf of the switchboard. These jacks and those on the face of the board are connected by means of two conductor flexible cords *j*, which terminate at one end in an ordinary two-conductor wedge and at the other end in a two-conductor plug.

From each spring jack in the shelf two wires run to an office set. The office set may be merely a main-line sounder *a*, or an ordinary Morse set *b* with a primary battery for operating the local sounder circuit, or a Morse set *c* with its local circuit operated by a 40-volt dynamo, or a combination Morse and duplex set *d* with a primary battery for operating its local sounder circuit, or a combination Morse and duplex set *e* with its local sounder operated by a 40-volt dynamo. By turning switches *k* and *l* to the right, sets *d* and *e* may be used as simple Morse sets, the receiving sounders *RS* being controlled by the corresponding relays. By turning switches *k* and *l* to the left, sets *d* and *e* may be used in a duplex loop, the repeating sounders *RS* being in the receiving leg and the keys and simple sounders *SS* being in the sending leg.

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NOTE.—All items in this index refer first to the section (see the Preface) and then to the page of the section. Thus, "Alphabet, Morse, §11, p3," means that the Morse alphabet will be found on page 3 of section 11.